ANNEX to GB decision no [.... /2022]

Clean Hydrogen JOINT UNDERTAKING (Clean Hydrogen JU)

WORK PROGRAMME 2022

Clean Hydrogen Partnership

In accordance with the Council Regulation (EU) 2021/2085 and with Article [xx] of the Financial Rules of the Clean Hydrogen Joint Undertaking.

The work programme is made publicly available after its adoption by the Governing Board.

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Acronyms and abbreviations

2Zero	Towards zero emission road transport Partnership
A/C	Aircraft
AC	Alternating current
AEL	Alkaline electrolysis
AEMEL	Anion Exchange Membrane
AEMEL	Anion Exchange Membrane Electrolysis
AFIR	Alternative Fuels Infrastructure Regulation
AIP	Approval in Principle
AIT	Auto Ignition
AWP	Annual Work Programme
B2B	Business-to-Business
B4P	Built4People European Partnership
BEV	Battery Electric Vehicles
BoP	Balance of plant
CAPEX	Capital up-front expenditure (investment)
CEF	Connecting Europe Facility
CEN	European Committee for Standardisation
CENELEC	European Committee for Electrotechnical Standardisation
CFD	Computational Fluid Dynamics
CINEA	European Climate Infrastructure and Environment Executive Agency
Co	Cobalt
CO	Carbon monoxide
CO_2	Carbon dioxide
CRM	Critical Raw Materials
CSA	Coordination and Support Actions
CTCN	Climate Technology Centre & Network, under the UN Environment Programme
D&E	Dissemination and Exploitation
DC	Direct current
DNI	Direct Normal Irradiance
EC	European Commission, sometimes also shortened to just Commission
EoL	End of Life
ED	Executive Director
EDA	European Defence Agency
EHS&CP	European Hydrogen Sustainability and Circularity Panel

EHSP	European Hydrogen Safety Panel
EIB	European Investment Bank
EIC	European Innovation Council
EL	Electrolyser
EPC	Engineering, procurement, and construction
ERA	European Research Area
ERDF	European Regional Development Fund
ETS	Emission trading system (also seen as EU ETS)
EU	European Union
EU ETS	EU Emission Trading System
EURAMET	European Association of National Metrology Institutes
FP	European Union's Framework Programmes for research and technological development. FP7 refers to the seventh programme (period 2007-2013), H2020 to the eighth (period 2014-2020), while Horizon Europe to the ninth (period 2021-2027)
FC	Fuel cell
FCEV	Fuel cell electric vehicle
FCH	Fuel cell and hydrogen
FCH (2) JU	Fuel Cells and Hydrogen Joint Undertaking. FCH 2 JU (2014-2020/Horizon 2020) succeeded FCH JU (2008-2014/FP 7) [1]
FCHO	Fuel Cell and Hydrogen Observatory, https://fchobservatory.eu/
FWC	Framework Contract
GB	Governing Board
GDL	Gas diffusion layer
GH_2	Gaseous Hydrogen
GHG	Greenhouse gas
GO	Guarantees of Origin
GT	Gas Turbine
GW	Gigawatt; GW_e refers to GW electric.
H_2	Hydrogen
H2020	Horizon 2020
H2O	Water
H2S	Hydrogen sulfide
H2V	Hydrogen Valley platform
HAZ	Heat Affected zones

[1] FCH JU was replaced by FCH 2 JU, which has taken over all rights and obligations of its predecessor. FCH 2 JU is now in turn replaced by the Clean Hydrogen Joint Undertaking.

HD	Heavy Duty
HDV	Heavy Duty Vehicles
HELLEN	Hydrogen Events and Lesson LEarNed
HER	Hydrogen Evolution Reaction
HHV	Higher heating value
HIAD	Hydrogen safety reference database
HOR	Hydrogen Oxidation Reaction
HRS	Hydrogen refuelling station
HTCP	Hydrogen Technology Collaboration Programme
HTE	High-Temperature Water Electrolysis
HTSE	High-Temperature Steam Electrolysis
IA	Innovation Actions
IACS	International Association of Classification Societies
ICE	Internal Combustion Engine
ICT	Information and communications technology
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IMO	International Maritime Organisation
IPCEI	Important Projects of Common European Interest
IPHE	International Partnership for Hydrogen and fuel cells in the Economy
IPR	Intellectual property rights
IRENA	International Renewable Energy Agency
ISO	International Organisation for Standardisation
IT	Information Technology
JRC	Joint Research Centre of the European Commission
JU	Joint Undertaking. For the scope of this document, when used as standalone, this acronym is used specifically to refer to the Clean Hydrogen Joint Undertaking. In all other instances or when not obvious the name Clean Hydrogen JU is used
kft	Kilofoot
kg	Kilogramme
KPI	Key performance indicator
kW	Kilowatt; kW_{th} refers to kW thermal.
kWh	Kilowatt-hour; kWh_e refers to kWh electric, while kWh_{th} to kWh thermal.
LAP	Legal and Administrative Processes
LCA	Life-cycle assessment

LCSA	Life-cycle sustainability assessment
LCI	Life Cycle Inventory
LCOH	Levelised Cost of Hydrogen
LDV	Light Duty Vehicles
LEL	Lower Explosive Limit
LFL	Lower Flammability Limit
LH_2	Liquid hydrogen
LHV	Lower heating value
LIN	Liquid Inert Nitrogen
LNG	Liquefied Natural Gas
LOHC	Liquid organic hydrogen carrier
LOI	Letters of Intent
LT-WE	Low Temperature Water Electrolysers
m^2, m^3	square meters, cubic meters
MEA	Membrane electrode assembly
MGA	Model Grant Agreement
MPL	Micro Porous Layer
MRL	Manufacturing Readiness Level
Mt	Million tonnes
MTBF	Mean time between failures
MW	Megawatt. MW_e refers to MW electric.
N2	Nitrogen
NDT	Non-destructive testing
Ni	Nikel
NO_x	Nitrogen oxides
NG	Natural Gas
NGO	Non-governmental organisations
O&M	Operation and Maintenance
OEM	Original equipment manufacturer
OER	Oxygen Evolution Reaction
OPEX	Operational expenditure
P4P	Processes 4 Planet Partnership
PBI	Polybenzimidazole
PCCEL	Proton Conducting Ceramic
PCCEL	Proton Conducting Ceramic Electrolysis
PDA	Project Development Assistance

PEM	Proton exchange membrane
PEMEL	Proton exchange membrane electrolysis
PEMFC	Proton exchange membrane fuel cell
PFAS	Per- and polyfluoroalkyl substances
PGM	Platinum group metals
PNR	Pre-normative research
PO	JU Programme Office
PPA	Power Purchase Agreement
Pt	Platinum
RA	Risk Assessment
R&I	Research and Innovation
R&D	Research and development
RCS	Regulations, codes and standards
RCS SC	Regulations, codes and standards Strategy Coordination
RED	Renewable Energy Directive
RES	Renewable energy sources
RIA	Research and Innovation Actions
RFNBO	Renewable fuels of non-biological origin
RRF	Recovery and Resilience Facility
rSOC	Reversible Solid Oxide Systems
RTO	Research and Technology Organisations
SBA	Single Basic Act, referring to the regulation establishing the Joint Undertakings under Horizon Europe
SET-Plan	Strategic Energy Technology Plan
SG	Stakeholder Group
SHM	Structural Health Monitoring
SME	Small and medium-sized enterprise
SoA	State-of-the-art
SOC	Solid Oxide Cells
SOE	Solid Oxide Electrolyser
SOEL	Solid Oxide Electrolysis (Cells)
SOFC	Solid oxide fuel cell
SRI	Strategic and comprehensive Innovation Roadmap
SRIA	Strategic Research and Innovation Agenda for 2021-2027 of the Clean Hydrogen Joint Undertaking (previously MAWP Multi-Annual Work Programme)

SRIA-HE	Strategic Research and Innovation Agenda for 2021-2027 of the Industry
SRG	State Representative Group
t	tonne
T&D	Transportation and Distribution
TC	Technical Committee
TCO	Total Cost of Ownership
TEN	Trans-European Network. TEN-E refers to Electricity, while TEN-T to Transport.
TIM	Tools for Innovation Monitoring
TPD	Tonnes per Day
TRL	Technology Readiness Level
UAV	Unmanned aerial vehicle
US, USA	United States of America
ZE	Zero Emission
ZEWT	Zero Emission Waterborne Transport Partnership

1 Work Programme 2022

1.1.1 Executive Summary

The first Annual Work Programme 2022 for the Clean Hydrogen JU will build on the previous work of its predecessor, FCH 2 JU, aligning it with the SRIA and its implementation strategy described in Section **Error! Reference source not found.**.

As the Clean Hydrogen JU was launched in the end of November 2021, it was not possible to launch a separate Call for Proposals that year. In 2022 one Call for Proposals with two cut-off dates for an indicative total budget of 300.5 million euros are foreseen. The Call addresses key challenges as identified by the stakeholders in the Clean Hydrogen JU. These challenges encompass different areas of research and innovation with direct and quantified impact towards the achievement of the objectives of the Clean Hydrogen JU in general and to each of the Pillars in particular. A total of 41 topics will be part of the call for proposals, including 10 for Renewable Hydrogen Production, 11 for Hydrogen Storage and distribution, 8 for transport and 4 for heat and power. In addition, 5 projects will support Cross-cutting issues. This call will also support 2 Hydrogen Valleys and 1 Strategic Research Challenge. They will be grouped into 10 Innovation Actions (IA), 29 Research and Innovation Actions (RIA) and 2 Coordination and Support Action (CSA). Five of the Innovation Actions considered of strategic importance and are selected as flagship projects. Synergies with other European partnerships and programmes as well as with Member States and regional programmes are at the core of a number of topics.

The Call for Proposals will be subject to independent evaluation and will follow the Horizon Europe rules on calls for proposals. Upon selection, the Partners (the ‘consortium’) will sign a Grant Agreement with the JU.

The Clean Hydrogen JU will continue to contribute towards the implementation of EU Policies through different means. It will continue following and contributing as necessary to the European Strategic Energy Technology Plan (SET-Plan)[2] activities, as well as support transport policies. On the latter, a study supported by the Clean Hydrogen JU on “Impact of Deployment of Battery Electric Vehicles (BEV) and Fuel Cells Electric Vehicles (FCEV) Infrastructure” should be finalized, while another on “Hydrogen in Ports and Industrial Coastal Areas” began early 2022. Moreover, the JU will examine its role in relation to the Alternative Fuels Infrastructure Regulation (AFIR) implementation. The CertifHy3 project aims at facilitating the creation of an EU-wide system of guarantees of origin for hydrogen. Finally, it remains ready to support the European Commission by cooperating with the European Clean Hydrogen Alliance.[3]

As part of the on-going framework contract with JRC, the annual Rolling Plan 2022 was agreed in 2021 and will be implemented in 2022. It consists of the annual activities and their related deliverables provided by JRC, which include the support to the regulations, codes and standards strategy and its implementation, its contribution to the Programme monitoring and assessment, the assessment of sustainability of hydrogen and fuel cells and the JRC contribution to safety, and safety awareness. As the framework contract will end in 2022, the Clean Hydrogen JU intends to sign a new framework contract with JRC in 2022 in the context of the current one, to ensure the continuity of services provided by JRC.

In terms of knowledge management, it will continue with the annual data collection exercise from its projects and the publication of the Programme Review Report, with the aim to

[2] https://ec.europa.eu/energy/en/topics/technology-and-innovation/strategic-energy-technology-plan
[3] https://ec.europa.eu/growth/industry/policy/european-clean-hydrogen-alliance_en

gradually extend it to other hydrogen projects funded by other partnerships or EU, national or regional funds. A procurement is foreseen for the continuation of the Fuel Cell and Hydrogen Observatory platform, providing data and up to date information for the entire hydrogen sector, with the current contract ending in April 2022. The continuous demand for more information and knowledge services may require a new platform, combining all platforms supported currently by the JU but with additional capabilities; the need will be examined in 2022 and the necessary steps will be taken. In terms of feedback to policy, the JU will continue contributing to the activities of the European Commission services as necessary.

Building already on experiences (and success stories) from the previous JUs, synergies have become a central piece of the 2021-2027 multi-annual financial framework. In 2022 we will further develop our structured cooperation with relevant European partnerships, EU agencies and other EU funding programmes, including those managed by national or regional Managing Authorities. Several procurements in 2022 have synergies in their scope and cooperation with other funding sources will be sought specially for the flagship topics (see further details in chapter on synergies later).

The regulations, codes and standards issues will continue to be addressed by the RCS SC group. In 2022, the RCS SC Group will continue with its main tasks, as laid out in its annual work plan, while redefining its structure/scope within the Clean Hydrogen JU.

Similarly, the European Hydrogen Safety Panel will also continue its activities, performing safety plan reviews, updating its guidance documents, providing guidance in developing areas (like heavy transport), performing public outreach and continuing with its data collection and assessment activities.

Considering the importance of strengthening the sustainability and circularity of hydrogen technologies, the Clean Hydrogen JU will set up EHS&CP at the Programme level. Its mission will be to assure these aspects are adequately addressed at Programme level, while also promote and disseminate the relevant knowledge and culture within and beyond the Programme.

The Clean Hydrogen JU will continue supporting the European Commission in its international cooperation activities. It will continue its work in relation to the harmonisation of the regulatory and policy frameworks, as well as safety and education. Moreover, it will continue its involvement in the IEA HTCP following a number of working groups. Finally, it will continue supporting the Hydrogen Valleys platform through a public procurement published on 10/12/2021,[4] while contributing also towards the other activities of Clean Hydrogen Mission under MI2.0.

Communication and outreach activities will ensure that stakeholders are duly informed about the Clean Hydrogen JU and ensure continuity in the transition from the FCH 2 JU, including getting the public accustomed to the new visual identity of the JU. The two new Calls will be strongly promoted to ensure high participation, while emphasis will also be given to an increased outreach effort to the general public with intensified awareness campaigns. A public procurement launched in 2021 for a Public Opinion Survey, to be signed in 2022, with the aim to gain insights into perceptions on the use of fuel cells and hydrogen technologies relating to a number of aspects will help further guide communication activities in the future.

As part of the knowledge management activities, but also in the context of the Project Management workflow, the Programme Office will continue its activities in dissemination and exploitation of project results. It will continue participating in the Innovation Radar, while will

[4] https://etendering.ted.europa.eu/cft/cft-display.html?cftId=9670

also promote other tools supporting further exploitation and dissemination.

As an EU body, the Clean Hydrogen Joint Undertaking will secure sound financial management of all its activities in accordance with the principles of the Internal Control Framework. In continuation of the work undertaken in previous years in the FCH 2 JU, corporate processes and procedures will be adapted to the provisions set forth in the Single Basic Act, and new ICT systems will be deployed over the year 2022, supporting both operational and administrative activities. The Clean Hydrogen JU will closely monitor the implementation of its budget and its Staff Establishment Plan and will continue its close cooperation with the other Joint Undertakings in matters of common interest.

Table 1: Correspondence of topics into the different scientific priorities

	1st cut-off date (31 May 2022)	2nd cut-off date (20 September 2022)
Renewable Hydrogen	TC1-01-A: Development and validation of pressurised high temperature steam electrolysis stacks (Solid Oxide Electrolysis) TC1-01-B: Development and validation of pressurised high temperature steam electrolysis stacks (Proton Conducting Ceramic Electrolysis) TC1-03: Development of low temperature water electrolysers for highly pressurised hydrogen production TC1-06: Efficiency boost of solar thermochemical water splitting TC1-07: Bringing green hydrogen MW scale off grid installations closer to technical and financial maturity TC1-09: Scaling-up technologies for SOEL	TC1-04: Design for advanced and scalable manufacturing of electrolysers TC1-05: Scaling up of cells and stacks for large electrolysers TC1-08: Integration of multi-MW electrolysers in industrial applications TC1-10: Demonstrating offshore production of green hydrogen
Hydrogen storage and distribution	TC2-03: Hydrogen and H2NG leak detection for continuous monitoring and safe operation of HRS and future hydrogen/H2NG networks TC2-04: Validation of a high-performance hydrogen liquefier TC2-08: Increased hydrogen capacity of GH 2 road trailers TC2-10: Development of novel or hybrid concepts for reliable, high capacity and energy-efficient H2 compression systems TC2-12: Sampling methodology and quality assessment of HRS at real-world scale TC2-13: Implementing new/optimised refuelling protocols and components for high flow HRS	TC2-02-B: Compatibility of Distribution non-steel metallic gas grid materials with hydrogen TC2-05-A: Ammonia to Green Hydrogen: efficient system for ammonia cracking for application to long distance transportations TC2-05-B: Efficient system for dehydrogenation of liquid organic hydrogen carriers for application to long distance transportations TC2-07-A: Development of large scale LH2 containment for shipping TC3-08: Development and demonstration of mobile and stationary compressed hydrogen refuelling solutions for application in inland shipping and short-distance maritime operations
Hydrogen end uses: transport applications	TC3-02: Innovative and optimised MEA components towards next generation of improved PEMFC stacks for heavy duty vehicles TC3-05: Large scale demonstration of European H2 Heavy Duty Vehicle along the TEN-T corridors	TC3-01: Development and optimisation of reliable and versatile PEMFC stacks for high power range applications

	1st cut-off date (31 May 2022)	2nd cut-off date (20 September 2022)
	TC3-06: LH2 tanks for heavy-duty vehicles TC3-09: Large scale demonstration of hydrogen fuel cell propelled inland waterway vessels TC3-10-A: Development and optimisation of a dedicated Fuel Cells for Aviation: from dedicated stack (100s kW) up to full system (MWs) TC3-10-B: Development and optimisation of a dedicated Fuel Cells for Aviation: disruptive next-gen high temperature Fuel Cells technology for future aviation TC3-11: Development of specific aviation cryogenic storage system with a gauging, fuel metering, heat management and monitoring system	
Hydrogen end uses: clean heat and power	TC4-02: Ammonia powered fuel cell system focusing on superior efficiency, durable operation and design optimisation TC4-03: Reversible SOC system development, operation and energy system (grid) integration TC4-04: Dry Low NOx combustion of hydrogen-enriched fuels at high-pressure conditions for gas turbine applications	TC4-01: Design and industrial deployment of innovative manufacturing processes for fuel cells and fuel cell components
Cross-cutting Issues	TC5-03: Safety of cryogenic hydrogen transfer technologies in public areas for mobile application TC5-06: Development of validated test methods and requirements for measuring devices intended for measuring NG/H2 mixtures EC-01: Research & Innovation co-operation with Africa on hydrogen	TC5-01: Public understanding of hydrogen and fuel cell technologies TC5-04: Safe hydrogen injection management at network-wide level: towards European gas sector transition
Hydrogen Valleys		FCH JU-02-A: H2 Valley (large-scale) FCH JU-02-B: H2 Valley (small-scale)

1.1.2 Calls for Proposals

1.1.2.1 Calls

The AWP 2022 includes one Call for Proposals with two cut-of dates as follows:

Call Identifier **HORIZON-JTI-CLEANH2-2022**	**Budget (EUR mill)**	**Opening**	**Deadline**
First cut-off date	179.50	01 March 2022	31 May 2022
Second cut-off date	121.00	01 March 2022	20 September 2022
Overall indicative budget	300.50		

Proposals are invited against the following topic(s):

Topic descriptions are detailed starting from the next page.

RENEWABLE HYDROGEN

TC1-01-A: Development and validation of pressurised high temperature steam electrolysis stacks (Solid Oxide Electrolysis)

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of around EUR 2.5 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 2.5 million.
Type of Action	Research and Innovation Action
Technology Readiness Level	Activities are expected to start at TRL 2 and achieve TRL 4 by the end of the project. See General Annex B.

<u>*Expected outcome*</u>

Hydrogen is stored, transported or used pressurised with variable pressures depending on user cases (e.g. between 7 and 70 bar for various industrial applications and grid injection, up to 200 bar for filling gas cylinders, as well as up to 350 and 700 bar in refuelling stations). Hydrogen compression requires energy, which negatively affects overall process efficiency and hydrogen molecule final cost. Pressurised electrolysis therefore has the potential to provide an efficient solution for delivery of pressurised hydrogen at reduced cost. It also enables a low emissions form of hydrogen production, including down to zero emissions if powered solely by renewables.

It is expected that this topic will provide breakthrough and game changing technologies for energy efficient pressurised hydrogen production using solid oxide electrolysers (SOEL) and contributing to the overall objective of the SRIA of the Clean Hydrogen JU, namely the hydrogen production cost of 3 €/kg by 2030.

The project outcomes will pave the way for the deployment of pressurised hydrogen production units using SOEL to accelerate uptake in one or more applications (e.g. injection into the gas grid, onsite production at hydrogen refuelling stations (HRS), feedstock for industry, such as steel plants, refineries, chemical plants).

The project results are expected to contribute to all of the following expected outcomes:

- Contributions to demonstration on stack level for a pressurised steam electrolysis solutions by 2025;
- Contributing to European leadership for renewable hydrogen production based on SOEL;
- Solutions for pressurised hydrogen production should vary from 5 bar to several hundreds. They will open new production of hydrogen for target applications that will be opened up (e.g., gas grid injection, HRS) at scale of minimum 10 kW operated in a laboratory or simulated environment for at least 2,000 hours;

- Contributing to defining use cases showing the applications and the benefits of the novel technology.

Project results are expected to contribute to all of the following objectives of the Clean Hydrogen JU SRIA:

- Reduction of CAPEX 2,000 €/(kg/d) and OPEX 130 € (kg/d)/y (of the overall system costs when also taking into account compression);
- Ensure circularity by design for materials and for production processes, minimising the life-cycle environmental footprint of electrolysers;
- Electricity consumption at nominal capacity of 39 kWh/kgH2;
- Heat demand at nominal capacity of 9 kWh/kgH2 by 2024;
- Stack current density 0.85 A/cm2;
- Stack pressure of at least 5 bar.

Scope[5]

Solid Oxide Electrolysis (SOEL) operating at 650-850°C, can be improved with pressurised operation. The integration of SOE stacks with balance of plant components proved the successful use of these systems at now significant scale (> 700 kW) and the road is paved towards MW scale thanks to a modular approach simplifying the scale-up step. However, these systems are designed for operating efficiently and durably at atmospheric pressure. There have been previous FCH JU projects[6] dedicated to pressurised High-Temperature Steam Electrolysis (HTSE) at small scale for SOE. Pressurised operation has been validated up to 30 bar at cell scale, and up to 15 bar at stack scale embedded in a pressure vessel[7]. These previous activities highlighted the need for more research efforts directed to the optimisation of components, cells and stacks to improve current density and stability in pressurised operation for SOEL technologies. Furthermore, additional efforts should focus on system integration and on defining optimal boundary operations for dedicated user cases in order to maximise the efficiency of the integrated scenarios (e.g. taking into account thermal integration and possible side stream products). This opens for the development of novel and/or improved systems concepts, where the benefits of pressurised electrolysis should be leveraged for deployment in large-scale centralised systems with economies of scale, hydrogen distribution to end uses, as well as distributed systems located at demand centres.

Proposals for this topic should set out a credible pathway to contribute to the development and validation of pressurised SOEL with technological breakthroughs aiming at designing and operating a stack at an optimal pressure with eventual assistance of a downstream compression process to reach higher delivery pressure. Electrochemical compression in the stack can also be considered. To tackle these challenges, the proposals should focus on system and stack design, as well as fabrication, assembly and testing of stack in the conditions suitable for the relevant business cases as follows:

- System design should be defined based on optimal integration of SOEL in selected

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[6] https://www.clean-hydrogen.europa.eu/projects-repository_en

[7] SOPHIA and HELMETH projects: https://www.clean-hydrogen.europa.eu/projects-repository_en

application(s) taking into account the operating limits of the SOEL. This activity will entail defining the optimal operating pressure of the stack and system to balance electricity consumption and heat demand at nominal capacity;

- A techno-economic evaluation of the SOEL integrated in given application(s) will provide Levelised Cost of Hydrogen (LCOH) of the pressurised SOEL system taking into account economy of scale and will be used to evaluate the impacts of the various modes of operation (e.g. atmospheric SOEL + pressurisation afterwards, pressurised SOEL, and combination of modes). Comparing the technology with e.g. other alkaline and PEM electrolysers, operating in pressurised mode using similar boundary limits will also provide insights into relevant business models. The proposals will furthermore aim at reaching the capital costs below 2,000 €/(kg/d). The project should also compare the efficiency gains between pressurised electrolyser and unpressurised with compressor for various system sizes;
- Stack designed for high current density (SOEL: 0.85 A/cm^2) should be successfully operated over one long term test of at least 2,000 hours and 4,000 hours of aggregated testing time in relevant pressurised operating conditions at a minimum of 5 bar and conforming to the envisaged use case;
- Degradation mechanisms and boundary operation of the stack and its components should be identified with respect to pressure, temperature, load, in stationary and transient conditions;
- Modelling should be used to support the development of cells and/or stacks.
- The stack(s) should be tested at scale of minimum 10 kW; the considered pressure will be selected in relation to the targeted use case (s) to minimise energy loss;
- The stack should be operated in representative conditions to evaluate its, as well as its durability during a 2,000 hours long term test. This should include some pressurisation/depressurisation cycles;
- The applicants should provide thorough analysis of safety aspects, such as safety shut-off, and focus on establishing smooth operation modes including pressurisation and depressurisation.

Consortia are expected to build on the expertise from the European research and industrial community to ensure broad impact by addressing several of the aforementioned items.

Proposals are expected to address sustainability and circularity aspects.

Activities developing test protocols and procedures for the performance and durability assessment of electrolysers and fuel cell components proposals should foresee a collaboration mechanism with JRC (see section 2.2.4.3 "Collaboration with JRC"), in order to support EU-wide harmonisation. Test activities should adopt the already published EU harmonized testing protocols to benchmark performance and quantify progress at programme level.

TC1-01-B: Development and validation of pressurised high temperature steam electrolysis stacks (Proton Conducting Ceramic Electrolysis)

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of around EUR 2.5 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 2.5 million.
Type of Action	Research and Innovation Action
Technology Readiness Level	Activities are expected to start at TRL 2 and achieve TRL 4 by the end of the project See General Annex B.

<u>*Expected outcome*</u>

Hydrogen is stored, transported or used pressurised with variable pressures depending on user cases, e.g., between 7 and 70 bar for various industrial applications and grid injection, up to 200 bar for filling gas cylinders, as well as up to 350 and 700 bar in refuelling stations. Hydrogen compression requires energy, which negatively affects overall process efficiency and hydrogen molecule final cost. Pressurised electrolysis therefore has the potential to provide an efficient solution for delivery of pressurised hydrogen at reduced cost. It also enables a low emissions form of hydrogen production, including down to zero emissions if powered solely by renewables.

It is expected that this topic will provide breakthrough and game changing technologies for energy efficient pressurised hydrogen production using Proton Conducting Ceramic Electrolysis (PCCEL) and contributing to the overall objective of the SRIA of the Clean Hydrogen JU, namely the hydrogen production cost of 3 €/kg by 2030.

The project outcomes will pave the way for the deployment of pressurised hydrogen production units based on proton conducting electrolyte to accelerate uptake in one or more applications (for example: injection into the gas grid, onsite production at HRS, feedstock for industry, such as steel plants, refineries, chemical plants).

The project results are expected to contribute to all of the following expected outcomes:

- Contributions to demonstration on stack level for a pressurised steam electrolysis solutions by 2025;
- Contributing to European leadership for renewable hydrogen production based on PCCEL;
- Solutions for pressurised hydrogen production will open new target applications (e.g. gas grid injection, HRS) contributing to defining user cases and showing the applications and benefits of the novel technologies

Project results are expected to contribute to all of the following objectives of the Clean Hydrogen JU SRIA:

- Reduction of CAPEX 2,000 €/(kg/d) and OPEX 130 €/(kg/d)/y (of the overall system costs when also taking into account compression.
- Ensure circularity by design for materials and for production processes, minimising the life-cycle environmental footprint of electrolysers;
- Achieving a current density of 0.5 A/cm2;
- Achieving a pressure at stack level of at least 5 bar;
- Faradaic efficiency above 90% at operational pressure and temperature.

Scope

For High Temperature Steam Electrolysis (HTSE), the Protonic Conducting Ceramic Electrolysis (PCCEL) operating at 500-700 °C can be a promising solution. PCCEL technology has emerged over the past decade with strong development in materials and cells research, while activities towards stack and system development have been marginal. There have been previous FCH JU projects dedicated to pressurised HTSE at small scale for PCCEL. For instance, pressurised PCCEL electrolysis cells with tubular geometry are showing high Faradaic efficiency (> 90%) and stable performance at 600°C up to 3 bar. These previous activities highlighted the needs for more research efforts directed to the optimisation of components, cells and stacks to improve current density and stability in pressurised operation for both technologies. Furthermore, additional efforts should focus on system integration and on defining optimal boundary operations for dedicated user cases in order to maximise the efficiency of the integrated scenarios (e.g. taking into account thermal integration and possible side stream products). This opens for the development of novel and/or improved systems concepts, where the benefits of pressurised electrolysis should be leveraged for deployment in large-scale centralised systems with economies of scale, hydrogen distribution to end uses, as well as distributed systems located at demand centres.

Proposals for this topic should set out a credible pathway to contribute to the development and validation of pressurised PCCEL with technological breakthroughs aiming at designing and operating a stack at an optimal pressure with eventual assistance of a downstream compression process to reach higher delivery pressure. Electrochemical compression in the stack can also be considered. To tackle these challenges, the proposals should focus on system and stack design, as well as fabrication, assembly and testing of stack in the conditions suitable for the relevant business cases as follows:

- System design should be defined based on an optimal integration of the PCCEL in selected application(s) while taking into account the operating limits of the PCCEL. This activity will entail defining optimal operating pressure of the stack and system to balance electricity consumption and heat demand at nominal capacity;
- A techno-economic evaluation of the PCCEL integrated in given application(s) will provide the Levelised Cost of Hydrogen (LCOH) of the pressurised PCCEL system taking into account economy of scale and will be used to evaluate the impacts of the various modes of operation. (e.g. atmospheric PCCEL + pressurisation afterwards, pressurised PCCEL, electrochemical compression in the PCCEL, and combination of modes) Comparing the technology with e.g. other alkaline and PEM electrolysers, operating in pressurised mode using similar boundary limits should also provide insights into relevant business models. The proposals should furthermore aim at reaching the capital costs below 2,000 €/(kg/d);
- The project should also compare the efficiency gains between pressurised

electrolyser and unpressurised with compressor for various system sizes and propose the most efficient solution;

- A stack designed for high current density (0.5 A/cm2), should be successfully operated over one long term test of at least 2,000 hrs and 4,000 hours of aggregated testing time in relevant pressurised operating conditions at a minimum pressure of 5 bar and conforming to the envisaged use case;
- Degradation mechanisms and boundary operation of the stack and its components should be identified and measured with respect to pressure, temperature, load, in stationary and transient conditions;
- Modelling should be used to support the development of cells and/or stacks;
- The stack(s) should be tested at scale of minimum 5 kW; the considered pressure will be selected in relation to the targeted use case (s) to minimise energy loss;
- The stack should be operated in representative conditions to evaluate its efficiency, as well as its durability during a 2,000 hours long term test. This should include pressurisation/depressurisation cycles;
- The applicants should provide thorough analysis of safety aspects, such as safety shut-off, and focus on establishing smooth operation modes including pressurisation and depressurisation.

Consortia are expected to build on the expertise from the European research and industrial community to ensure broad impact by addressing several of the aforementioned items.

Proposals should demonstrate how they go beyond the ambition of WINNER and GAMER projects[8] and be complementary to them.

Proposals are expected to address sustainability and circularity aspects.

Activities developing test protocols and procedures for the performance and durability assessment of electrolysers and fuel cell components proposals should foresee a collaboration mechanism with JRC (see section 2.2.4.3 "Collaboration with JRC"), in order to support EU-wide harmonisation. Test activities should adopt the already published EU harmonized testing protocols to benchmark performance and quantify progress at programme level.

[8] https://www.clean-hydrogen.europa.eu/projects-repository_en

TC1-02: Development of low temperature water electrolysers for highly pressurised hydrogen production

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of around EUR 2.5 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 5.00 million.
Type of Action	Research and Innovation Action
Technology Readiness Level	Activities are expected to start at TRL 2 and achieve TRL 5 by the end of the project See General Annex B.
Procedure	The procedure is described in General Annex F. The following exceptions apply: To ensure a balanced portfolio covering complementary approaches, grants will be awarded to applications not only in order of ranking but at least also to one additional project that is / are complementary, provided that the applications attain all thresholds.

<u>*Expected Outcome*</u>

The current generation of Low Temperature Water Electrolysers (LT-WE) are demonstrated on a large scale and are ready for mass production. However, to reduce the Levelised Cost of Hydrogen (LCOH) and to make renewable hydrogen competitive with hydrogen from fossil sources, continuous improvements to LT-WE systems that avoid energy and cost intensive downstream mechanical compression processes, especially in the first stages, are required. Therefore, to maintain and accelerate the European leadership position in water electrolysis technology and innovation in the whole supply chain, new research and innovation (in parallel to upscaling) are crucial in the electrolyser stack design as whole and the different critical components including Balance of Plant (BoP).

Low temperature water electrolysers are expected to produce hydrogen at high pressure (from 50 to 80 bar), accelerating the adoption in several applications such as gas grid injection, as well as utilisation in the chemical industry and at hydrogen refuelling stations (HRS), circumventing the initial compression stages.

Project results are expected to contribute to all of the following expected outcomes:

- Contributing to keep European leadership for pressurised hydrogen production including innovative embedded compression approaches based on: Alkaline (AEL) or Proton Exchange Membrane (PEMEL) or Anionic Exchange Membrane (AEMEL) Electrolyser systems;
- Contributions to full scale demonstrators by 2027;
- New business models for end use applications such as hydrogen injection in the existing gas grid and utilisation in the chemical industry;

- A boost for future dedicated transmission gas network and methanol ammonia production while strengthening EU supply chain and HRS developers.

Project results are expected to contribute to all of the following objectives of the Clean Hydrogen JU SRIA:

- Improving efficiency by 2-4% (lower heating value, LHV) compared to the use of a mechanical compressor 0.5kWh for mechanical compression of 1kg H2 from 30 to 80 bar;
- Increase system reliability and significantly reduce compression energy needs resulting in an overall lower levelised cost of hydrogen (LCOH) below 3 €/kg once integrated in the multi-MW electrolyser platform assuming 40 €/MWh and 4,000 full load hours operation;
- Demonstrate the value of electrolysers for the power system through their ability to allow higher integration of renewables.

Research findings and outcomes at stack and balance of plant level will contribute to speed up the reduction of the levelised cost of hydrogen. Proposals should investigate the high-pressure effects on the overall electrolysis process, since the increase of gas solubility might reduce the dynamic operating range while increase the corrosion/degradation of the materials.

Some of the barriers to be addressed are in line to novel design concepts and compatible materials while finding some high-pressure specific components might be challenging.

Research will contribute to a faster achievement towards the 2024 KPIs of the Clean Hydrogen JU SRIA, whilst allowing electrolysers to a fully integrated operation with renewable energy sources (RES) and direct gas grid connection and limiting the use of critical raw materials and precious metals as oxygen evolution reaction (OER) and hydrogen evolution reaction (HER) catalysts or replace them completely with other (more) available metals.

The project results will also contribute to speed up the achievement of some of the key 2024 KPIs of the Clean Hydrogen JU SRIA for LT-WE according to the following figures for each technology:

- AEL, Electricity consumption @ nominal capacity (kWh/kg) 49, Degradation (%/1,000 hrs) 0.11, Minimum pressurisation levels (bar) 50, Minimum stack size (kW) 50;
- PEMEL, Electricity consumption @ nominal capacity (kWh/kg) 52, Degradation (%/1,000 hrs) 0.15, Minimum pressurisation levels (bar) 80, Minimum stack size (kW) 50;
- AEMEL, Electricity consumption @ nominal capacity (kWh/kg) 53, Degradation (%/1,000 hrs) 0.9, Minimum pressurisation levels (bar) 50, Minimum stack size (kW) 25.

Due to the higher pressure, the temperature may also be raised to above 100°C, which will in turn drastically reduce the H_2 production energy consumption contributing to reduction in overall hydrogen production costs.

Scope

High-pressure electrolysers should be compatible with direct injection into chemical industry and gas networks both onshore and offshore as the avoidance of mechanical compressors are of crucial importance to reduce the LCOH and improve the availability of systems. The developed electrolysers may reach low LCOH for both centralised and decentralised applications due to the unique modular approach.

The scope of this project is to develop the next generation of water electrolysers (PEMEL or AEMEL) operating below 150 ºC for pressurised hydrogen production at the pressure of minimum 50 bar for AEL and AEMEL and 80 bar for PEMEL further advancing innovations developed in projects[9] like NEPTUNE and PRETZEL.

To this extent, breakthroughs in materials science of cell components should encompass advances in the cell design, cell architecture and BoP modules. This requires a completely new design enabling: low energy consumption and low degradation rates while contributing to reduce the hydrogen production costs.

Novel stack concepts should be designed, whilst innovations in BoP (e.g., integration of innovative compression solutions with electrolyser stacks), advanced materials and components (membranes/diaphragms, porous transport layers, bipolar plates, catalyst) developed and integrated into a short-stack prototype.

Targeted prototype scale and cell size should be appropriate for targeted application but a scale of minimum 50 kW for AEL and PEMEL and 25 kW for AEMEL, including larger cell areas than SoA, should be addressed.

Proposals should demonstrate how the concepts developed will be validated in a laboratory (TRL4) but should also include testing in relevant environment (TRL5) to pave the way for end-use applications (e.g. technology could be tested for injection in transmission natural gas grid). This includes the validation at the single cell and stack levels, testing the components at nominal, steady state and dynamic conditions and identifying a best candidate solution.

Operations at elevated pressures should be validated under various operating conditions (understood as directly scalable to multi-MW electrolysers) in order to develop new control strategies and to optimise operation at high-pressure and evaluate the effect of pressure in the case of hot starts and cold starts.

Proposals should investigate the high-pressure effects on the overall electrolysis process, both with respect to the effect of increased gas solubility, bubble-formation and the effect on electrode overpotentials and ohmic losses as well as the associated increase in gas cross-over at elevated pressures.

Optimal stack and cell design in terms of structure and geometry (e.g. spacing distances within the cell) should be within the scope of proposals.

Research on corrosion effects on the cells and/or lifetime prediction model and mitigation strategies should be conducted in order to maintain lifetime and degradation.

Proposals are expected to address sustainability and circularity aspects.

Activities developing test protocols and procedures for the performance and durability assessment of electrolysers and fuel cell components proposals should foresee a

[9] https://www.clean-hydrogen.europa.eu/projects-repository_en

collaboration mechanism with JRC (see section 2.2.4.3 "Collaboration with JRC"), in order to support EU-wide harmonisation. Test activities should adopt the already published EU harmonized testing protocols[10] to benchmark performance and quantify progress at programme level.

[10] https://www.clean-hydrogen.europa.eu/knowledge-management/collaboration-jrc-0_en

TC1-03: Design for advanced and scalable manufacturing of electrolysers

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of around EUR 2.00 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 4.00 million
Type of Action	Research and Innovation Action
Manufacturing Readiness Level	Activities are expected to start at MRL 4 and achieve MRL 5 by the end of the project See Call management and general conditions section.
Procedure	The procedure is described in General Annex F. The following exceptions apply: To ensure a balanced portfolio covering complementary approaches, grants will be awarded to applications not only in order of ranking but at least also to one additional project that is / are complementary, provided that the applications attain all thresholds

<u>*Expected Outcome*</u>

The huge leap expected in the evolution of water electrolyser technology can be performed only by reaching significant technical and economic targets. The European Hydrogen strategy targets 6 GW installed electrolyser capacity by 2024 ramping up to 40 GW electrolyser capacity by 2030. To achieve such targets, both products and production processes should undergo a significant enhancement, by means of strong cost reduction program, as well as improved automation and technologies. Such upgrades can be applied to the several steps of manufacturing, starting from the single electrolyser cell to the stack assembly. Therefore, it is necessary that the whole manufacturing chain is involved in this cost reduction/performance improvement of the electrolyser stacks required to produce enough renewable hydrogen to fulfil the EU targets, similarly to the on-going manufacturing development of fuel cells (e.g. slot die coating for Catalyst Coated Membrane, plasma spray, roll-to-roll coaters).

The project should aim to find the best compromise between CAPEX and OPEX[11] costs to minimise the cost of produced hydrogen, also considering the output pressure.

At the end of the project the achievement of the target figures described in detail above should be demonstrated. The outcome should be a novel component(s) or manufacturing process(es) integrated in a demonstrator stack. The scalability of the final demonstrator and the cost targets of hydrogen should be clearly proven with a business plan.

Project results are expected to contribute to all the following expected outcomes:

- Improving efficiency by 2-4% LHV compared to the use of the present state of the art

[11] O&M costs

solutions;

- Increase system reliability and significantly reduce manufacturing costs resulting in an overall lower CAPEX and reaching a projected levelized cost of hydrogen (LCOH) below 3 €/kg after the scaling up of the foreseen manufacturing techniques;
- Demonstrate the value of advanced manufacturing techniques to reduce manufacturing times enhancing printing or assembly tolerances versus the state of the art.

To address the above-mentioned cost system targets, the project is focusing on stack/components manufacturing and should at least reach the 2024 KPIs stack targets (degradation, current density, limited use of Critical Raw Materials) included in the Clean Hydrogen JU SRIA. Project results are expected to contribute to all of the following objectives of the Clean Hydrogen JU SRIA as summarised below.

- AEL Degradation (%/1,000 hrs) 0.11, Current density (A/cm2) 0.7, Use of CRMs as catalysts (Mg/W) 0.3;
- PEMEL Degradation (%/1,000 hrs) 0.15, Current density (A/cm2) 2.4, Use of CRMs as catalysts (Mg/W) 1.25;
- AEMEL Degradation (%/1,000 hrs) 0.9, Current density (A/cm2) 0.6, Use of CRMs as catalysts (Mg/W) 0.4;
- SOEL Degradation (%/1,000 hrs) 1, Current density (A/cm2) 0.85.

European R&D institutions and hydrogen-related companies should join their efforts to reach the following targets provided by the system costs Key Performance Indicators (KPIs), which have been set for all the major electrolysis processes (Alkaline Electrolysis (AEL), Proton Exchange Membrane Electrolysis (PEMEL), Solid Oxide Electrolysis (SOEL), Anion Exchange Membrane Electrolysis (AEMEL):

- The capital costs per system, calculated on 100MW production volume for a single company, are expected to drop well below 1,000 €/kW for all technologies (AEL capital costs should decrease at least to 480 €/kW, aiming at 400 €/kW; PEMEL capital costs should decrease at least to 700 €/kW, aiming at 500 €/kW; SOEL capital costs should at least be below 1,000 €/kW, aiming at 700 €/kW; AEMEL should aim to 300 €/kW);
- The operational and maintenance costs (O&M) should also be reduced, by means of an increased reliability of the stack and the application of advanced monitoring systems, i.e. predictive maintenance (AEL O&M costs should decrease at least below 50 €/(kg/d)/yr; PEMEL O&M costs should decrease at least to 30 €/(kg/d)/yr, aiming to 20 €/(kg/d)/yr; SOEL O&M cost should decrease at least to 130 €/(kg/d)/yr, aiming to 45 €/(kg/d)/yr; AEMEL O&M cost should aim to 20 €/(kg/d)/yr).

Scope

Proposals should aim to significant and innovative improvements of the manufacturing processes to achieve the expected KPI targets. The changes can involve both the manufacturing of components of the single unit (e.g. innovative materials and processes) and the assembly of a whole stack (e.g. automation). Integrated quality control and monitoring systems are also included.

The following items are in scope of this topic and should lead to cost reduction and cell/stack reliability improvement. Scalability should be considered for each of the research paths to be followed in the project. The project should consider the re-use and recycling of the electrolysers and their components at their end of life. Proposals should address at least 3 of the topics below:

- Alternatives and/or novel processes should be identified, allowing improved conduction coatings with impact on Platinum group metals (PGM) content. Catalysts should be reduced in water electrolysers, since they are both very expensive and CRMs;
- Exploration of new surface coating technologies and advanced manufacturing processes (e.g., 3D printing) for more efficient mass production, which can allow higher current density and process efficiency;
- Improvement of manufacturing throughput, feature control, and scale for electrolyser bipolar plates to be coupled with a reduction of the processing cost through cost-effective and mass production-friendly processing techniques, including forming, punching, cleaning, coating and other processes;
- Reduction of the manufacturing steps and transportation costs required to fabricate porous transport layers/gas diffusion layers;
- Improvement of the level of automation of the cell stacks assembly thanks to the development of robotics tooling and automated inspection;
- Test and development of scalable predictive maintenance devices which can greatly reduce the O&M costs of the electrolyser stack;
- Include process design to leverage the recyclability of the materials at the end of life and the utilisation of recycled materials in novel manufacturing on a circularity approach.

Consortia should include at least one electrolyser OEM, one actor from the manufacturing sector and at least one SME.

Consortia are encouraged to consider some of the best practices from the fuel cell manufacturing sector not yet adopted in the electrolyser manufacturing and that could be beneficial to it. In addition, consortia are encouraged to explore synergies and cooperation with Made in Europe partnership (Cluster 7).

Proposals are expected to address sustainability and circularity aspects. In particular, circularity and sustainability by design concepts should be holistically considered towards the whole technology chain.

TC1-04: Scaling up of cells and stacks for large electrolysers

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of around EUR 6.00 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 6.00 million.
Type of Action	Research and Innovation Action
Technology Readiness Level	Activities are expected to start at TRL 3 and achieve TRL 5 by the end of the project. See General Annex B.

<u>*Expected Outcome*</u>

This topic concerns the research and development of much larger cells and stacks for water electrolysers than the current State of the Art (SoA). By upscaling electrolyser cells and stacks, economies of scale can be realised in manufacturing and more compact installations can be achieved when integrating electrolysers into industrial chemical processes, thermal processes and hydrogen hubs. Achieving all of the 2024 KPI targets stated in the SRIA of the Clean Hydrogen JU for low-temperature electrolysers will ease the adoption of renewable hydrogen by existing industrial processes and facilitate the introduction of renewable hydrogen production at scale. Furthermore, the research findings and outcomes at cell, stack and balance of plant level are expected to advance the subsequent deployment of large electrolysers to help satisfy the 2030 target of 40 GW renewable hydrogen electrolysers included in the European Hydrogen Strategy[12] and contribute to speeding up the achievement of key 2030 KPIs specified in the Clean Hydrogen JU SRIA.

Project results are expected to contribute to all of the following expected outcomes:

- Innovations will be delivered with respect to the design and construction of electrolyser cells and stacks, which have considerably larger active areas and operate at higher current densities than the existing SoA;
- The performances of a number of prototype test stacks based on these cells will be assessed in order to establish the viability of building a single stack of nominally 10 MW capacity. This will fill a knowledge gap concerning the feasibility of large cells and stacks and prepare the way for subsequently demonstrating a 10MW electrolyser module (including appropriate balance of plant);
- A techno-economic evaluation should be undertaken of electrolyser systems, of approximately 50-1,000MW scale, comprising assemblies of this electrolyser module for use in identified industrial processes and other large-scale applications.

Project results are expected to help maintain European leadership in the field of electrolysis and contribute to all of the following objectives of the Clean Hydrogen JU SRIA:

[12] https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf

- Develop larger area cells/stacks components with adequate manufacturing quality for high power systems;
- Improve cell design for high performance and increase cell/stack robustness;
- demonstrate that electrolysis technology, when deployed at scale, has the potential to meet cost and performance KPIs;
- reducing electrolyser CAPEX and OPEX;
- Increasing current density;
- Increasing the scale of deployment.

In particular, the developed electrolyser stacks should conform with the 2024 KPI targets of the Clean Hydrogen JU SRIA, corresponding to the type of low-temperature electrolyser technology that is being developed, as per the list below.

- AEL, Electricity consumption @ nominal capacity (kWh/kg) 49, CAPEX €/(kg/d) 1,000, OPEX €/(kg/d)/y 43, Current density (A/cm2) 0.7, Use of critical raw materials as catalysts (mg/W) 0.3;
- PEMEL, Electricity consumption @ nominal capacity (kWh/kg) 52, CAPEX €/(kg/d) 1,550, OPEX €/(kg/d)/y 30, Current density (A/cm2) 2.4, Use of critical raw materials as catalysts (mg/W) 1.25.

Scope

The application of electrolysers to industrial clusters and hydrogen hubs in order to achieve substantial CO_2 savings is inhibited by the present capacities of electrolyser stacks. Hydrogen production could be achieved more cost effectively if larger electrolyser cells and stacks were available. When compared with the current SoA, the development of an electrolyser module of about 10MW, if feasible, would be a considerable step-forward (where a module comprises the least number of stacks and preferably only one stack). However, there are several R&I challenges which first need to be overcome to realise this. Proposals are expected to address the following:

- Scale-up of cell active areas by a factor of at least two, operating at higher current densities and increasing the number of cells per stack, while ensuring durability and performance (mechanically, electrically and in terms of heat and mass transfer) for the envisaged balanced pressure or differential pressure stack;
- Ensure the catalyst and electrode production techniques achieve uniform performance for the required cell areas;
- Develop appropriate production methods and supply chains for larger cell plates and electrodes;
- Establish any technical limits that may restrict the achievable cell size, current density or stack size for a large electrolyser;
- Establish the extent of cost reductions, relative to a SoA stack, when innovating larger cells and stack;
- Ensure a good match between the design of the stack assembly and the power supply unit to minimise energy losses and the overall cost of the electrolyser module;
- Appropriately scale-up of the balance-of-plant while ensuring a compact design for the electrolyser module;

- Minimise weight and footprint to ensure ease of handling and shipping;
- Maximise the overall cost reduction potential by minimising parts count and value engineering;
- Build and test several short stacks, based on large cells, in order to establish the feasibility of subsequently building an electrolyser module of 10MW capacity comprising preferably a single stack;
- Identifying any optimal sizes for larger cells and stacks from scientific, engineering, logistics and economic perspectives.

Activities developing test protocols and procedures for the performance and durability assessment of electrolysers and fuel cell components proposals should foresee a collaboration mechanism with JRC (see section 2.2.4.3 "Collaboration with JRC"), in order to support EU-wide harmonisation. Test activities should adopt the already published EU harmonized testing protocols[13] to benchmark performance and quantify progress at programme level.

[13] https://www.clean-hydrogen.europa.eu/knowledge-management/collaboration-jrc-0_en

TC1-05: Efficiency boost of solar thermochemical water splitting

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of around EUR 4.00 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 4.00 million.
Type of Action	Research and Innovation Action
Technology Readiness Level	Activities are expected to start at TRL 4 and achieve TRL 6 by the end of the project. See General Annex B.

Expected Outcome

In order to ramp up renewable hydrogen production in the future, a suitable portfolio of diverse technologies is needed to serve the expected growing demand for different applications and markets. Since hydrogen technologies will be deployed on a broad range of markets and scales, abundant and cheap renewable energy resources need to be used. Solar energy has by far the highest potential of all options. In this context, solar thermochemical cycles may contribute to complement the electrochemical solar hydrogen production. Proposals under this topic aim to bring thermochemical cycles to the next stage of maturity.

Project results are expected to contribute to all of the following expected outcomes:

- Diversify the portfolio of technologies for the generation of renewable hydrogen;
- Mitigate mid-to-long term risks of renewable hydrogen availability shortage through diversifying the technology options;
- Enable solar thermochemical cycles as a viable and competitive hydrogen production technology;
- Foster awareness and acceptance of renewable hydrogen production technologies.

Project results are expected to contribute to all of the following objectives of the Clean Hydrogen JU SRIA:

- Reaching solar-to-hydrogen energy conversion efficiencies higher than 10% (daily average based on higher heating value (HHV) and direct normal irradiance (DNI);
- Ensuring hydrogen production cost < 5 €/kg for a scaled plant in multi-MW size;
- Improving the efficiency of processes: average hydrogen production rates higher than 0.75 kg/year per m^2 land area used (equivalent of 2.16 kg/day/m^2 (receiver area) for a solar concentration factor of about 1,000);
- Reducing CAPEX and OPEX: System capital cost in k€/kg/day (15.19 by 2024 and 7.41 by 2030); System operational cost in €/kg (0.59 by 2024 and 0.30 by 2030);
- Provide a technology with materials and all components scalable to multi-MW-scale.

Scope

Thermochemical cycles can directly convert heat into chemical energy by a series of chemical reactions. The direct application of solar heat in water-splitting thermochemical cycles for renewable hydrogen production allows operating at relatively moderate to upper temperatures, reducing electricity consumption and also reducing production cost. Main technical challenges to be addressed are increasing the solar-to-hydrogen efficiency through process intensification, especially through highly efficient internal heat transfer and recovery as well as the scalability of the reactor concept to achieve high energy conversion efficiencies and high throughput. Two stages of development are foreseen for thermochemical cycles and for achievement of the indicated targets and KPIs.

The most promising and advanced solar thermal and hybrid water-splitting processes are those based on metal oxide cycles or on sulphur cycles (thermal and hybrid ones), where prototypes of core components and core production chain elements have been developed and tested at solar towers. Those cycles are attractive since they involve only few chemical steps with low complexity, leading to high reversibility and potentially high cycle efficiency.

One of the central measures to reach intermediate targets in terms of efficiency and cost is the improvement of heat management. It is necessary to recover and reuse a significant portion of the high temperature heat in order to increase the process efficiencies thus making the systems more attractive for commercial use. Several approaches for such heat recovery systems are currently under consideration and development. Proposals should demonstrate how they intend to address this.

Proposal should also address the heat recuperation from solid and gas phase by enhancing heat and mass transfer especially in the reactor using suitably structured porous materials and also in other units of the process via the usage of suitable heat transfer media like gases or particles.

Proposals should demonstrate on-sun operation of a prototype plant system (including key components) in a relevant environment (typically between 50 and 300 kW) for at least 6 months operation time (net operation time; only day time operation) reaching average hydrogen production rates higher than 0.75 kg/year per m^2 land area used (equivalent of 2.16 kg/day/m^2 (receiver area) for a solar concentration factor of about 1,000).

Proposals should develop smart operation and control strategies as well as pathways to scale the technology to the multi-MW scale using modelling and simulation of the plant and key components.

To tackle the above, proposals should consider the following:

- improvement of heat management via efficient heat recovery systems;
- improvement of coupling the process to a concentrating solar energy source ("solar interface");
- shaping the solar field towards the needs of a chemical process;
- wherever possible, the coupling to heat storage;
- integration of smart control procedures as a central measure to incorporate aspects on digitalisation of the energy system;
- explore suitable options for decreasing the production cost through hybrid renewable supply;
- develop suitable 3-dimensional structuring of key materials like redox materials to achieve high production rates and high reactor efficiencies through optimal heat and

mass transfer in the reactor;

- ensure stability and performance of key components and related properties of their constituent functional materials;
- consider the circular economy aspects like the recycling/regeneration of the materials and low content of Critical Raw Materials;
- optimised fluids handling, including the minimisation of inert gas consumption, the efficiency of gas separation operations, and auxiliary power needs;
- describe and validate upscaling strategies of the process and all major components.

Proposals are encouraged to seek collaboration with the existing or upcoming projects of the European Innovation Council (EIC) Pathfinder Challenge on novel routes to green hydrogen production[14]. In particular, applicants should consider building on the breakthrough technologies and advance thermochemical processes developed in these projects.

Proposals are expected to address sustainability and circularity aspects.

[14] https://eic.ec.europa.eu/eic-funding-opportunities/calls-proposals/eic-pathfinder-challenge-novel-routes-green-hydrogen_en

TC1-06: Bringing renewable hydrogen MW scale off grid installations closer to technical and financial maturity

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of around EUR 9.00 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 9.00 million.
Type of Action	Innovation Action
Technology Readiness Level	Activities are expected achieve TRL 7 by the end of the project. See General Annex B.
Admissibility conditions	The conditions are described in General Annex A. The following exceptions apply: The page limit of the application is 70 pages.
Eligibility condition	The conditions are described in General Annex B. The following additional eligibility criteria apply: At least one partner in the consortium must be a member of either Hydrogen Europe or Hydrogen Europe Research. The maximum Clean Hydrogen JU contribution that may be requested is EUR 9.00 million – proposals requesting Clean Hydrogen JU contributions above this amount will not be evaluated.
Legal and financial set-up of the Grant Agreements	The rules are described in General Annex G. The following exceptions apply: Purchases of equipment, infrastructure or other assets used for the action must be declared as depreciation costs. However, for the following equipment, infrastructure or other assets purchased specifically for the action (or developed as part of the action tasks): electrolyser and other hydrogen related equipment essential for implementation of the project, (e.g. compression of hydrogen, storage and any essential end-use technology) costs may exceptionally be declared as full capitalised costs.

<u>Expected Outcome</u>

Off-grid locations offer an attractive opportunity to incorporate new Renewable Energy Sources (RES) into the energy system without requiring an electricity grid infrastructure to connect the electrolyser system; and in addition grid fees are avoided. Such locations can be remote areas where the grid cannot be easily deployed, or places where the grid is weak, or it is already saturated with renewable sources. The hydrogen produced in these locations is unquestionably renewable hydrogen and would allow demonstrating its use for seasonal energy storage and industry uses. Furthermore, the development and improvement of such renewables and hydrogen integrated systems can play an important role for energy communities and distributed energy models, not only inside the EU but also in locations with relevant renewable energy production capacity and limited grid development, like Northern Africa. There are two main barriers to overcome in an off-grid hydrogen production site, (i.e. cost and efficient energy management), and projects at the scale of several MW are now required to tackle these barriers.

Projects are expected to contribute to all of the following expected outcomes:

- Installation of electrolysers to decarbonise existing hydrogen production in locations where the electricity grid is unavailable, weak or saturated;
- Allowing increased amounts of renewable generation through optimised integration between RES, electrolysers and large-scale hydrogen storage improving flexibility, efficiency and cost.
- Showcase the role of electrolysis in locations with insufficient infrastructure for connecting electrolysers to the grid, where RES feed-in or electrolyser connections are limited by grid capacity constraints, or where grid fees are an economic barrier;
- Understanding the complexities of design, commissioning, and operation of MW size projects in off-grid environments with the aim to reduce technical and financial risks of similar projects;
- Direct coupling of large-scale renewable and hydrogen production installations involving optimisation of overall system conversion efficiency. Investigation of potential changes in renewable technologies as well as hydrogen technologies;
- Obtaining a representative comparison in cost and hydrogen production and storage of off-grid vs on-grid electrolysis, also considering scenarios where hydrogen is transported (either on-shore, or also to or from off-shore) instead of electricity to hydrogen consumption points;
- Identification of the optimal balance between RES power installed, stack power, H2 production and storage;
- Showcase the versatility of hydrogen as an efficient energy storage tool for balancing production/demand applied to different end uses cases;
- Stimulation of the development of new Renewable Energy Supply (RES) in local "renewable hydrogen valleys" where local produced energy is also used locally;
- Determining the opportunities and restrictions of off-grid electrolysis, including the impact of the absence of grid- and transport fees while adding hydrogen storage costs;
- Increasing awareness and support for local renewable hydrogen production and consumption, including models to increase share benefits of local RES with the local community;
- Identification of appropriate business models for reducing costs and accelerating the transition to decarbonisation for various sectors;
- Learnings on off-grid renewable hydrogen generation at large scale in areas with existing gas infrastructure e.g. pipelines and to underground storage, islands and remote areas, and an assessment of the time-varying interactions between hydrogen production, storage and end use;
- To become the seed of an “off-grid” hydrogen valley.

Project results are expected to contribute to all of the following objectives of the Clean Hydrogen JU SRIA:

- MW scale direct coupling to renewable generation (both on- and off-grid) including offshore hydrogen production, aiming at identifying the best system configuration to reach competitiveness.

Project results will also contribute to speed up the achievement of some of the KPIs of the Clean Hydrogen JU for LT-WE according to the following figures for each technology:

- AEL, Hot idle ramp time (sec) 30, Cold start ramp time (sec) 900, electricity consumption @ nominal capacity (kWh/kg) 49, Degradation (%/1,000h) 0.11, Current density (A/cm2) 0.7, Use of critical raw materials as catalysts (mg/W) 0.3;
- PEMEL, Hot idle ramp time (sec) 1, Cold start ramp time (sec) 10, electricity consumption @ nominal capacity (kWh/kg) 52, Degradation (%/1,000h) 0.15, Current density (A/cm2) 2.4, Use of critical raw materials as catalysts (mg/W) 1.25.

Scope

The main objective of this topic is to demonstrate the complete value chain of off-grid hydrogen production, storage and end-use installations at MW scale.

In regions of high renewable resource where the electricity grid is either heavily utilised or non-existent, off-grid hydrogen production provides the only opportunity for harnessing renewable energy at scale. Off-grid electrolysers should be designed to be coupled directly to variable solar/wind power sources and survive periods of zero power generation and poor weather, without recourse to the electricity grid. In this way they can access renewable electricity at least cost, by avoiding the usual fees and tariffs that are imposed for grid connection by grid operators, electricity suppliers and regulators. The combination of high renewable resource and low-cost electricity suggests that hydrogen could be produced at low cost, provided that suitable off-grid electrolysers are developed.

The electrolyser function cannot rely on a stable energy source (AC grid); it has to perform across the whole range of operation with high flexibility and use advanced control systems to efficiently utilise the time-varying renewable electricity input. The electrolyser system needs to include some energy storage (eg. by incorporating batteries, hydrogen storage and fuel cells) to ensure that the electrolyser is always protected during dormant periods (especially freezing weather conditions) and is ready to operate as soon as the renewable generation begins. More development is needed to achieve better ratios of BoP/stack power at all ranges of operation, looking for improvement in the electricity consumption of components (intensity) during operation, in order to realise cost-effective and efficient off grid electrolyser solutions. Also, further development is needed to find optimised and cost-efficient system architectures for the coupling between RES and the system. Direct connection of the RES source to the stack (DC/DC) has been satisfactorily demonstrated for units at 50 kW scale in a strict off-grid environment (TRL 6), obtaining 97% of efficiency across the whole range of operation, which makes the scale up to MW scale feasible by adapting the design to cope with higher input voltages and currents. Modifications to be applied to renewables technologies in terms of DC/DC conversion are also conceivable, and suitable ways to include batteries for safe stand-alone operation can be explored.

To optimise the efficiency, cost reduction, flexibility, and reliability (security of supply) of the whole value chain adding hydrogen storage (or hydrogen transport in comparison to electricity transport), it is essential to support the role of electrolysis in off-grid configuration. In this respect, optimisation of the control strategy and alignment with the storage system specifics (and other components of the value chain) to improve overall system efficiency and lifetime for the complete facility has to be taken into consideration. Projects should provide a preliminary analysis for relevant geographical regions, including country-specific challenges, a sustainability assessment for the environmental impact, social acceptance, as well as economic feasibility.

The participation of inter- and trans-disciplinary consortia combining expertise and capacity covering both renewables and hydrogen technologies from public authorities, industrial stakeholders, infrastructure providers, knowledge institutions, planners, entrepreneurs, societal actors and citizens is advised to address the challenges.

In addition, proposals should address the following aspects:

- As the aim of the topic is to cover the whole value chain and depending on the application the cost of certain components may be more relevant than others, the following ranges are to be considered. Size of electrolysis system: 3 to 5 MW. Minimum size of hydrogen storage: 4 tonnes;
- Proposals should be oriented to optimise the performance of the system, with particular attention paid to the effects on electrolyser's efficiency and degradation rate on hydrogen production, as well as to power conversion, system control and other critical parameters. The KPI values as indicated above should be achieved at the end of the project, with the exception of the capital cost KPI. It is recognised that the cost of a MW scale off-grid electrolyser system may be significantly different to that of a grid-connected electrolyser of the same size;
- Proposals should secure downstream use, and it should include integration with enough storage to match discontinuous generation with hydrogen end uses. The end use of the hydrogen should be included and clarified in the proposal including a viable business case. All decisions relating to pressurised or atmospheric electrolyser operation, the use of compressors, and the amount and type of hydrogen storage should be justified;
- Proposals should also build upon knowledge and experience from relevant previously funded FCH JU projects[15];
- Proposals should consider periods for scheduled maintenances of the system and estimate the performance of the system on that period;
- Strict off-grid conditions are desirable, although connection to the grid for testing, control and safety reasons can be foreseen;
- The system (demonstrator) developed by the project should operate for at least one complete year. This includes the complete value chain covering off-grid hydrogen production, storage, and end use.

Costs of equipment besides the electrolyser can be considered eligible as long as proposals demonstrate that they are essential for implementation of the project, e.g. compression of hydrogen, storage and any essential end-use technology. Costs related to the development of renewable energy technologies specifically designed for off-grid hydrogen production, e.g. a hydrogen producing wind turbine, would also be considered eligible.

[15] https://www.clean-hydrogen.europa.eu/projects-repository_en

This topic is expected to contribute to EU competitiveness and industrial leadership by supporting a European value chain for hydrogen and fuel cell systems and components.

Proposals should provide a preliminary draft on ‘hydrogen safety planning and management’ at the project level, which will be further updated during project implementation.

It is expected that Guarantees of origin (GOs) will be used to prove the renewable character of the hydrogen that is produced. In this respect consortium may seek out the issuance and subsequent cancellation of GOs from the relevant Member State issuing body and if that is not yet available the consortium may proceed with the issuance and cancellation of non-governmental certificates (e.g CertifHy[16]).

Activities developing test protocols and procedures for the performance and durability assessment of electrolysers and fuel cell components proposals should foresee a collaboration mechanism with JRC (see section 2.2.4.3 "Collaboration with JRC"), in order to support EU-wide harmonisation. Test activities should adopt the already published EU harmonized testing protocols to benchmark performance and quantify progress at programme level.

[16] https://www.certifhy.eu/

TC1-07: Integration of multi-MW electrolysers in industrial applications

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of around EUR 18.00 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 18.00 million.
Type of Action	Innovation Action
Technology Readiness Level	Activities are expected to start at TRL 6 and achieve TRL 8 by the end of the project. See General Annex B.
Admissibility conditions	The conditions are described in General Annex A. The following exceptions apply: The page limit of the application is 70 pages.
Eligibility	The conditions are described in General Annex B. The following additional eligibility criteria apply: At least one partner in the consortium must be a member of either Hydrogen Europe or Hydrogen Europe Research.
Legal and financial set-up of the Grant Agreements	The rules are described in General Annex G. The following exceptions apply: Purchases of equipment, infrastructure or other assets used for the action must be declared as depreciation costs. However, for the following equipment, infrastructure or other assets purchased specifically for the action (or developed as part of the action tasks): electrolyser, its BoP and any other hydrogen related equipment essential for the implementation of the project (e.g. hydrogen storage) costs, may exceptionally be declared as full capitalised costs.

Expected Outcome

This flagship[17] project is expected to pave the way for further large-scale integration of electrolyser systems in industrial applications in the framework of fully commercial operations. The project should demonstrate in an operational industrial environment improved electrolysis technology at a scale of >25MW, configured to provide the necessary reliability of supply at the lowest possible cost of bulk renewable hydrogen to one or more hydrogen users. It will prove the integration of multi-MW state of the art electrolysers into industrial applications, showing decreased costs for both CAPEX and OPEX, increased operational reliability, improved integration both within the industrial process plant and with an associated renewable energy power plant/power purchase agreement (PPA) (as per regulatory requirements) to ensure high reliability. SRIA KPIs for 2024 for the relevant

[17] For definition of flagship see section 5.3. of the Clean Hydrogen JU Strategic Research and Innovation Agenda 2021 – 2027

technology should be met.

Moreover, the project shall prove important additional technological advancement compared to the Djewels[18] project, as well as the three projects that have been selected in the context of the Green Deal call on the 100 MW electrolysers[19] under Horizon 2020.

Project results are expected to contribute but are not limited to the following expected outcomes:

- Emphasise innovation aspects that demonstrate how electrolyser technology goes beyond the current state of the art, while ensuring replicability and wide commercial impact following the implementation of the project;
- Demonstrate reliable operation of large-scale electrolysis and the use of the produced hydrogen in an application valorising the renewable character of the produced hydrogen according to final user's requirements;
- Gain operational experience, including safety and regulatory framework, of the contractual and hardware arrangements required to distribute and supply hydrogen to the specific industrial environment;
- Perform techno-economic analysis of the performance of these systems showcasing the business case of the proposed solution;
- Technically assess the operation of the electrolyser in the industrial environment regarding contractual and hardware arrangements and suggest best practices;
- Evaluate the life cycle environmental performance of the system in alignment with the applicable regulation, defining renewable hydrogen with attention to the CO_2 intensity of the hydrogen produced, which should include an understanding of the CO_2 footprint impact in the addressed hydrogen end-user markets;
- Identify the value and size of the markets addressed and the possibility of indirectly affecting additional relevant markets;
- Assess the legislative and RCS implications of these systems and any issues identified in obtaining consents to operate the system;
- Make recommendations for policy makers and regulators on measures helping to maximise the value of renewable energy and stimulate the market for renewables-electrolyser systems.

Project results are expected to contribute to all of the following objectives of the JU as reflected in the SRIA:

- AEL, Electricity consumption @ nominal capacity (kWh/kg) 49, Capital cost €/(kg/d) 1,000, O&M cost €/(kg/d)/y 43, Degradation (%/1,000h) 0.11, Current density (A/cm2) 0.7, Use of critical raw materials as catalysts (mg/W) 0.3;
- PEMEL, Electricity consumption @ nominal capacity (kWh/kg) 52, Capital cost €/(kg/d) 1,550, O&M cost €/(kg/d)/y 30, Degradation (%/1,000h) 0.15, Current density (A/cm2) 2.4, Use of critical raw materials as catalysts (mg/W) 1.25.

[18] https://www.clean-hydrogen.europa.eu/projects-repository_en

[19] https://cordis.europa.eu/search?q=contenttype%3D%27project%27%20AND%20programme%2Fcode%3D%27LC-GD-2-2-2020%27&p=1&num=10&srt=/project/contentUpdateDate:decreasing

Scope

The project should aim at demonstrating electrolyser technologies beyond actual state-of-the-art producing hydrogen reliably under favourable economic conditions in a specific industrial application to be chosen by the applicants.

The scope of the project is to demonstrate the integration of a large-scale electrolyser of minimum 25 MW. Technical requirements in terms of purity and pressure shall be designed to fulfil the industrial requirements. At least 2 years of operation are expected. Hydrogen production should be >1,500 tonne/yr and the facility should be working more than 3,200 equivalent hours/yr at full load;

Proposal should address innovation aspects that ensure the project goes beyond the state of the art. Examples of innovations could include, but are not limited to:

- Possibly supply hydrogen to two separate users, each with their own operational requirements and managing electrolyser output both in terms of generation and storage in order to maximise the efficiency of the setup;
- Use oxygen and/or waste heat from the electrolyser for other processes at the industrial site, or from the industrial process to the electrolyser in case of SOEL;
- Concepts related to the circular economy (e.g.: re-use of CO_2 at the site);
- Provision of grid services that help the economics of the installation;
- Footprint reduction, for example integrating hardware vertically instead of horizontally, or minimising the footprint of the electrolyser with a single balance of plant including all required utilities such as water purification, power rectification with appropriate grid interfaces and hydrogen purification, process cooling, etc;

Given that the topic leaves the possibility open for addressing a broad scope of industrial applications, it will be up to the proposal to clearly specify these innovation aspects and avoid any duplication of previous industrial electrolyser applications. In this regard, proper reference and complementarity to previously funded projects by the FCH JU (e.g. Refhyne, H2Future, Djewels, Multiplhy, MegaSyn) and the Green Deal 100MW electrolyser projects should be included, if applicable;

Proposals should also:

- Satisfy industrial requirements for round-the-clock operation using an otherwise (a priori) intermittent source of primary renewable energy;
- demonstrate the economic benefits/enablers of the project for the selected applications. The consortium should demonstrate/investigate a sustainable long term business case for industrial customers who value the renewable character of the hydrogen. This should include a study on the impact of using renewable hydrogen on the final cost of the product and a market evaluation to understand how much premium the end customers are willing to pay for a renewable product;
- Provide the operating scenarios, the expected annual production, the use(s) foreseen and a detailed business case analysis. The electrolyser and downstream systems should be installed and operated for a minimum period of two years within the duration of the project; assurances for operation thereafter should be provided at the proposal stage;
- Include a plan for use of the installation after the project;

- Disseminate the technical and economic benefits, notably (but not only) to the communities of the relevant Horizon Europe private-public partnerships;
- Describe how learnings will be communicated and dissemination will occur beyond the consortium, including those regions in Europe where large scale electrolysis has not yet been demonstrated;
- Support the development of the EU value chain and competitiveness of EU industry for electrolysers, including main components, cells and stacks.

The power connection costs, building costs and the electricity costs for the commissioning phase are eligible for funding. Electricity costs during demonstration / business operation are not eligible. The results of a techno-economic assessment should be reported after each year of operation, including information on the individual cost and revenue streams related to the electrolyser.

The project shall include a clear go/no-go decision point (milestone) ahead of entering the deployment phase. Before this go/no go decision point, the project shall deliver the following: detailed engineering plans, a complete business and implementation plan and all the required permits for the deployment of the project. The project proposal is expected to clearly demonstrate a proposed pathway to obtaining necessary permits for the demonstration actions and allow for appropriate timelines to achieve these.[20]

This topic is expected to contribute to EU competitiveness and industrial leadership by supporting a European value chain for hydrogen and fuel cell systems and components.

Applicants are encouraged to seek collaboration with existing projects of the Horizon Europe Process4Planet partnership or future topics concerning innovative industrial processes, that could make use of the hydrogen produced by the electrolyser.

Proposals are expected to address sustainability and circularity aspects.

Proposals should provide a preliminary draft on ‘hydrogen safety planning and management’ at the project level, which will be further updated during project implementation.

It is expected that Guarantees of origin (GOs) will be used to prove the renewable character of the hydrogen that is produced. In this respect consortium may seek out the issuance and subsequent cancellation of GOs from the relevant Member State issuing body and if that is not yet available the consortium may proceed with the issuance and cancellation of non-governmental certificates (e.g CertifHy[21]).

Activities developing test protocols and procedures for the performance and durability assessment of electrolysers and fuel cell components proposals should foresee a collaboration mechanism with JRC (see section 2.2.4.3 "Collaboration with JRC"), in order to support EU-wide harmonisation. Test activities should adopt the already published EU harmonized testing protocols to benchmark performance and quantify progress at programme level.

[20] independent experts will assess all deliverables and will give advice on the go/no go decision.
[21] https://www.certifhy.eu/

TC1-08: Scaling-up technologies for SOEL

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of around EUR 3.00 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 6.00 million
Type of Action	Research and Innovation Action
Technology Readiness Level	Activities are expected to start at TRL 4 and achieve TRL 6 by the end of the project See General Annex B.
Procedure	The procedure is described in General Annex F. The following exceptions apply: To ensure a balanced portfolio covering complementary approaches , grants will be awarded to applications not only in order of ranking but at least also to one additional project that is / are complementary, provided that the applications attain all thresholds

<u>*Expected Outcome*</u>

To decarbonise industries, but also as an energy vector, hydrogen can play a major role, but its production needs to be scaled up in the GW scale.

High Temperature Steam Electrolysis (HTSE) technology using Solid Oxide Electrolysis Cells (SOEL), thanks to its high efficiency, has the potential to become a game changer technology for the massive production of hydrogen at low cost. However, its maturity remains one step behind alkaline and Proton Exchange Membrane (PEM) water electrolysis. Currently, the largest demonstration unit installed has a power of 720 kW (GrinHy 2.0 project), while there is a plan to install and operate in the frame of MULTIPLHY[22] project a unit of 2.4 MW by the end of 2022. In contrast, units of MWs or tens of MW are already installed or planned to operate shortly for the two other electrolysis technologies. In addition, the unit size of SOEL cells, stacks, and modules remains small, as compared to other electrolysis technologies, which might not be optimal from both a technical and economical point of view in order to address a massive hydrogen production market with multi-MW units. Indeed, small cells and stacks require the assembly and integration of a large number of stacks to reach the high power targeted, which makes system integration more complex.

For SOEL to reach this scale, increasing the size of the cell, stack and module size, as well as the current density and lifetime, can be undertaken to accelerate the accomplishment of the targeted footprint and CAPEX and possibly OPEX goals.

The expected outcome of the present topic is to move forward the maturity of the technology by:

- Developing and validating upscaled cells, larger stacks, and their assembly into enlarged modules;

[22] https://www.clean-hydrogen.europa.eu/projects-repository_en

- Designing the integration of these enlarged pieces into a multi-MW scale electrolysis unit;
- Enabling hydrogen production costs of < 3 €/kg for such a multi-MW scale plant by 2030, jointly establishing relevant business models;
- Paving the way for the deployment of large-scale hydrogen production units.

Project results are expected to contribute to the following expected outcomes:

- Contributions to at least two full scale demonstrators (MW) for SOEL technology by 2027;
- Maintain European leadership on SOEL technologies that will be applicable for massive hydrogen production;
- Solutions for enlarged cells, stacks and modules demonstrated and validated in relevant environments;
- New business models for SOEL technology based on upscaled components;
- Breakthrough and game changing technologies for SOEL upscaled components;
- Foster the replication of the solutions developed in the project as demonstration units;
- Strengthen the European value chain on cells, stacks, modules and systems by encouraging vertical partnerships;
- New products addressing/targeting massive hydrogen production.

Project results are expected to contribute to all of the following objectives of the Clean Hydrogen JU SRIA:

- Reducing electrolyser CAPEX to 2,000 €/(kg/d) and OPEX to 130 €/(kg/d)/y by 2024;
- Decreasing footprint to 150 m^2/MW or less, this being considered as an average specific space requirement of a MW system comprising all auxiliary systems;
- The performance and lifetime for enlarged cells and stack should present performance and lifetime not below that of the reference cells and stack. Current density should be at least 0.85 A/cm^2 and degradation at thermoneutral voltage at or below 1%/1,000 hours;
- Reaching an electricity consumption at nominal capacity of 39 kWh/kg H2 produced;
- Ensure circularity by design for materials and for production processes, minimising the life-cycle environmental footprint of electrolysers;

<u>*Scope*</u>

The proposal should focus on the scalability of cells, stacks and modules, namely in terms of design, cells and stack manufacture and their assembly into modules as well as on operation in environment suitable for the selected applications and business cases as follows:

- Identify the optimal sizes for larger cells and stacks from both techno-economical and practical point of view. Pinpoint any technical limits that may restrict the achievable size and the extent of cost reductions when innovating larger cells and stacks;
- Identify the optimal stack assembly layout into modules of > 250 kW capacity, as well

as the assembly of such modules into multi-MW units;

- Based on this work, perform a thorough techno-economic analysis considering economies of scale and scalability of manufacturing processes to show that project developments allow reaching the CAPEX and OPEX KPI targets included above in order to pave the way to reach a Levelized Cost of Hydrogen (LCOH) of 3 €/kg, or under, by 2030;
- Operate successfully the cells of the optimal defined size or arrangement in the repeat unit as estimated by the action indicated above for high current density and low degradation as set out in the KPI targets included above, over 2,000 hours in relevant operating conditions;
- Validate, in terms of performance and durability over 2000h, stacks or assemblies of stacks in series to increase the power at the optimal defined size;
- Demonstrate appropriate production methods and supply chains for larger cells and stacks;
- Build a downscaled module of at least 80 kW of power. Upstream and downstream BoP components in relation to the targeted use case(s) should be included to minimise energy losses and the overall cost of the electrolyser module;
- Operate this 80-kW system in representative conditions to evaluate its efficiency (including stack and BoP components), as well as its durability for at least 2,000 h.

Proposals are expected to address sustainability and circularity aspects.

Activities developing test protocols and procedures for the performance and durability assessment of electrolysers and fuel cell components proposals should foresee a collaboration mechanism with JRC (see section 2.2.4.3 "Collaboration with JRC"), in order to support EU-wide harmonisation. Test activities should adopt the already published EU harmonized testing protocols[23] to benchmark performance and quantify progress at programme level.

[23] https://www.clean-hydrogen.europa.eu/knowledge-management/collaboration-jrc-0_en

TC1-10: Demonstrating offshore production of renewable hydrogen

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of around EUR 20.00 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 20.00 million
Type of Action	Innovation Action
Technology Readiness Level	Activities are expected to start at TRL 5 and achieve TRL 7 by the end of the project See General Annex B.
Admissibility conditions	The conditions are described in General Annex A. The following exceptions apply: The page limit of the application is 70 pages.
Eligibility	The conditions are described in General Annex B. The following additional eligibility criteria apply: At least one partner in the consortium must be a member of either Hydrogen Europe or Hydrogen Europe Research.
Legal and financial set-up of the Grant Agreements	The rules are described in General Annex G. The following exceptions apply: Purchases of equipment, infrastructure or other assets used for the action must be declared as depreciation costs. However, for the following equipment, infrastructure or other assets purchased specifically for the action (or developed as part of the action tasks): electrolyser, its BOP and any other hydrogen related equipment essential for implementation of the project (e.g. offshore infrastructure, renewable electricity supply infrastructure, storages, pipelines and other auxiliaries required to convey and utilise the hydrogen), costs may exceptionally be declared as full capitalised costs.

Expected Outcome

The European Commission's "Strategy to Harness the Potential of Offshore Renewable Energy for a Climate Neutral Future"[24] expects renewable energy projects to become increasingly important in most sea basins in Europe, including innovative projects such as offshore hydrogen production. Hydrogen may be produced offshore by achieving an association between wind turbines and electrolysers by various approaches. These include retrofitting an electrolyser to an existing oil & gas platform, building a renewable hydrogen production hub on a man-made island, building a new platform close to a wind farm, or integrating the electrolyser and wind turbine into one offshore assembly. The electricity may be supplied via a private wire, a grid connection, or off-grid. Moreover, offshore produced

[24] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0741&from=EN

hydrogen may be exported via existing repurposed or new pipelines (gas blended or pure hydrogen) or by dedicated ships; and a platform may be used for grid balancing and for refuelling ships offshore.

This topic calls for a flagship project demonstration at multi-MW scale, >5MW, of the feasibility of offshore renewable hydrogen production. This may be achieved by either re-using existing offshore electricity/oil/gas infrastructure or using new infrastructure, to export energy as hydrogen rather than electricity and so support the greater integration of renewable power sources into the energy system. It is expected that the electrolyser operation will closely follow the wind power generation profile. This will be one of the first worldwide demonstrations of an offshore multi-MW system integration for renewable hydrogen production and export/use.

Project results are expected to contribute to all of the following outcomes:

- Achievement of a step change regarding experience with the additional safety aspects of hydrogen production offshore and export/use, de-risking future projects and investments;
- Determination of the long-term performance of an offshore electrolyser in terms of integration capabilities, efficiencies, systems balancing, performance degradation, operational cost;
- Evaluation and demonstration of operational, inspection and maintenance requirements of offshore electrolysis process;
- Building upon existing experience and research into suitable offshore renewable hydrogen infrastructures and expanding this knowledge;
- Enabling further roll-out of offshore renewable hydrogen production and export/use;
- Acting as a stepping stone for dedicated offshore electrolysis coupled with windfarms, transporting renewable energy as renewable hydrogen, or the offshore use of renewable hydrogen;
- Provide relevant experience to retrofitting existing electricity/oil/gas offshore infrastructure demonstrating their feasibility and cost competitiveness in the long run.

Proposals should aim to improve understanding of the technical, economic, regulatory and operational benefits and hurdles of producing and exporting offshore renewable hydrogen with direct connection to offshore windfarms.

Project results are expected to contribute to all of the following objectives of the Clean Hydrogen JU SRIA:

- AEL, Electricity consumption @ nominal capacity(kWh/kg) 49, Degradation (%/1,000h) 0.11, Hot idle ramp time (sec) 30, Cold start ramp time (sec) 900;
- PEMEL, Electricity consumption @ nominal capacity(kWh/kg) 52, Degradation (%/1,000h) 0.15, Hot idle ramp time (sec) 1, Cold start ramp time (sec) 10.

Scope

This Innovation Action flagship[25] topic will aim to demonstrate offshore production and export/use of hydrogen as a first multi-MW step towards large-scale offshore renewable hydrogen production. The scope covers process design, engineering, construction, procurement, integration with offshore infrastructure and operation of a >5MW electrolysis system at an offshore setting. This can include the supply of renewable electricity, water at the required specification as well as cooling, drying, compression, storages, pipelines and other auxiliaries required to convey and utilise the hydrogen. Accordingly, the project will incur substantial integration costs, both upstream and downstream of the electrolyser, in addition to the costs of the offshore electrolyser itself.

Proposals should address the following:

- Deployment of a system that is designed to be remotely controlled, monitored and autonomously operated to minimise operational costs, while also allowing ready access for essential maintenance purposes;
- Evaluation of the operational, inspection and maintenance requirements of offshore electrolysis systems;
- Operation of the offshore electrolyser and hydrogen export/storage/use for two complete seasonal cycles (24 months). Projects should record all relevant operating data (e.g.: electricity input, hydrogen production and export, system degradation, system fault/trips and root cause analysis) to allow the feasibility of offshore renewable electrolysis to be fully assessed;
- Determination of the performance of the offshore electrolyser in terms of efficiency, performance degradation, operational and maintenance costs;
- If relevant to the electrolyser site, an assessment of economic impact of re-using existing offshore infrastructure compared with developing new offshore infrastructure. KPIs regarding accommodation ratios (MW/m^2), cost of installed production (€/MW), etc, shall be defined as appropriate in the proposals to build the assessment;
- A techno-economic comparison of the chosen approach to offshore hydrogen production and transport by pipeline with an otherwise similar approach on land that is based on onshore wind power;
- Assessment of the efficient use of the available renewable energy and of the best control strategies to optimise the plant performances based on the measured process operation data. For this purpose, proposals shall define KPIs regarding availability, efficiency, LCOH, etc;
- Assessment of the environmental impact in terms of avoided CO_2 emissions resulting from the utilisation of the renewable hydrogen produced offshore. A preliminary estimation of the CO_2 avoided emission is expected already in the proposal;
- Describe how learnings will be communicated and dissemination will occur beyond the consortium, including regions in Europe with significant potential for offshore renewable hydrogen production.

The offshore conditions, stringent safety requirements, securing a renewable electricity supply, EPC requirements, and the difficult accessibility makes this call very challenging compared with land-based deployments of electrolysers in the electricity grid. Hence to

[25] For definition of flagship see section 5.3. of the Clean Hydrogen JU Strategic Research and Innovation Agenda 2021 – 2027

address adequately the challenges of this project, the consortium should assess:

- Technical and specific hydrogen expertise for the design, provision, integration, safety and operation of the offshore electrolysis process devices and associated hydrogen export/use
- The necessary contractual and commercial expertise to market the hydrogen;
- The end-use of the produced and exported hydrogen;
- The potential sustainability of the deployed renewable production plant beyond the demonstration phase;
- Obtaining the necessary permitting and regulatory approvals as required for the timeframe of the project;
- Legal, safety and regulatory expertise related.

Proposals are expected to demonstrate important additional technological advancement compared to the FCH JU project OYSTER[26].

This topic encourages the deployment of sustainable transportation of hydrogen methods by soliciting the planning of «medium range and backbone transmission infrastructures» in line with the "Hydrogen Strategy for a Climate Neutral Europe[27]". In addition, it is important that the offshore production of hydrogen conforms with Europe's general commitment to achieving and maintaining clean and healthy oceans by addressing the operation, recyclability, recovery and re-use of offshore electrolysers[28].

The following costs are considered to be eligible for funding: the design, development, procurement, integration and installation of the offshore electrolyser and its water supply; the electrolyser's electricity connection; the auxiliary systems (including hydrogen storage and export infrastructure); the commissioning, operation and maintenance of the deployed system for the demonstration phase. Costs associated with offshore infrastructure acquisition or retrofitting, buying electricity and electricity grid levies for the demonstration phase are not eligible.

Applicants should be able to demonstrate the compatibility of their proposal with a wider perimeter, such as renewable electricity production, export/use means and/or platform infrastructure. Additional funding streams and match funding are encouraged.

This topic is expected to contribute to EU competitiveness and industrial leadership by supporting a European value chain for hydrogen and fuel cell systems and components.

Proposals should provide a preliminary draft on 'hydrogen safety planning and management' at the project level, which will be further updated during project implementation.

It is expected that Guarantees of origin (GOs) will be used to prove the renewable character of the hydrogen that is produced. In this respect consortium may seek out the issuance and subsequent cancellation of GOs from the relevant Member State issuing body and if that is not yet available the consortium may proceed with the issuance and cancellation of non-governmental certificates (e.g CertifHy[29]).

Activities developing test protocols and procedures for the performance and durability

[26] https://www.clean-hydrogen.europa.eu/projects-repository_en
[27] https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf
[28] https://ec.europa.eu/oceans-and-fisheries/ocean/clean-and-healthy-oceans_en#ecl-inpage-101

[29] https://www.certifhy.eu/

assessment of electrolysers and fuel cell components proposals should foresee a collaboration mechanism with JRC (see section 2.2.4.3 "Collaboration with JRC"), in order to support EU-wide harmonisation. Test activities should adopt the already published EU harmonized testing protocols to benchmark performance and quantify progress at programme level.

TC2-02-B: Compatibility of Distribution non-steel metallic gas grid materials with hydrogen

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of around EUR 2.5 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 2.5 million.
Type of Action	Research and Innovation Action
Technology Readiness Level	Activities are expected to start at TRL 3 and achieve TRL 5 by the end of the project. See General Annex B.

Expected Outcome

In its strategic vision for a climate-neutral EU (to meet the carbon neutrality in 2050) presented by the European Commission on 28th November 2018, the share of hydrogen in Europe's energy mix is projected to grow from the current less than 2% to 13-14% by 2050. In order for hydrogen to claim such position in the energy mix and as explicitly mentioned in the EU Hydrogen Strategy[30], it is essential that hydrogen becomes an intrinsic part of an integrated energy system. Hydrogen will have to be used for daily or seasonal storage providing buffering functions thereby enhancing security of supply in the medium term. The strategy also calls for an EU-wide logistical infrastructure that needs to be developed in order to transport hydrogen from areas with large renewable potential to demand centres across Europe. Consequently, a pan-European grid will have to be established.

To do so there is significant energy system benefit in using existing natural gas assets across Europe, as they have large seasonal storage potential and can also readily manage large swings in daily demand. To supply this hydrogen, European gas grid operators aim to increase the content of hydrogen blends into natural gas from in existing gas grids (including transmission and distribution gas networks but also by extension their connections to hydrogen production facilities and new end users). In parallel, European gas grid operators also work on repurposing existing assets to transport 100% hydrogen.

Considering these challenges, project results are expected to contribute to all of the following expected outcomes:

- De-risking of business case for repurposing of existing European gas grids for hydrogen and enabling expansion of new dedicated infrastructures for pure hydrogen;
- Increased operator, regulator, authorities, and end user confidence in safety of repurposed gas grids by consolidated and exhaustive scientific data;
- Making available harmonised guidelines to assess the hydrogen effect on metallic materials present in the gas grids to get a complete view of network

[30] https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf

compatibility. These guidelines would provide inputs to pre-normative actions conducted through European organisations and enable a seamless interconnection between gas grids.

Project results are expected to contribute to all of the following objectives of the Clean Hydrogen JU SRIA:

- Development of technologies and materials to facilitate the transportation of hydrogen via the natural gas grid.
- Enable through research and demonstration activities the transportation of hydrogen through the natural gas grid either by blending or via repurposing to 100% hydrogen.

Scope

Former public bibliographic results and testing programs (e.g. NaturalHY[31], HYready[32], MultiHy[33] or Higgs[34] projects) have identified an embrittlement effect on steel grid materials used for pipes or network equipment, directly linked to the partial pressure of hydrogen (commonly expressed in terms of percentage of hydrogen in the total volume of gas at a specific pressure). However, this embrittlement effect on the various metallic materials used on the gas distribution networks (steel, but also cast iron, copper, lead…) has not been documented to date, as most existing testing programs have investigated non-metallic materials only. Therefore, there is a strong need to document the effect of hydrogen on metallic materials at low pressure, taking into account the great diversity of existing networks across the European Union, in terms of material grades used, building protocols (e.g. welds) or day-to-day current and future operational parameters (e.g. pressure level).

All types of metallic materials (steel, cast iron, copper, brass, lead, aluminium) or operational parameters representative of the functioning of the distribution networks have not been fully studied. All gas grids characteristics and load case scenarios should be covered to better assess the lifespan of existing infrastructure.

Currently different standards can be used for the design of metallic components (ISO 11114-4, ASME B31.12) or to assess their mechanical properties in the presence of hydrogen (ANSI/CSA CHMC 1, ASTM G142). This wide range of standards and the lack of commonly agreed mechanical guidelines are slowing down the definition of harmonised criteria to assess hydrogen-readiness of European gas networks.

Proposals should therefore focus on all non-steel metallic materials constitutive of Distribution networks (such as cast iron, copper, brass, lead, aluminium etc.).

In particular proposals should:

- Deliver a preliminary inventory of non-steel metallic materials constitutive of the European distribution natural gas grid and deliver a priority ranking analysis to evaluate the most cost-efficient strategy (adaptation or replacement) for each of them;
- Propose a testing approach covering most relevant non-steel metallic grades (cast iron, copper, brass, lead, aluminium) constitutive of European distribution natural gas grids and their different operating conditions (maximum pressure, pressure cycling, etc.). Proposals should cover an extensive range of natural gas/hydrogen blends with

[31] https://cordis.europa.eu/project/id/502661/es
[32] https://www.gerg.eu/project/hydrogen/
[33] https://cordis.europa.eu/project/id/263335
[34] https://www.clean-hydrogen.europa.eu/projects-repository_en

a focus on hydrogen contents up to 20%, and 100%. This approach should combine mechanical tests and modelling, e.g. using first principles calculations or fracture mechanics method of hydrogen interaction with the materials. A preliminary bibliographic review should be conducted to identify the gap analysis at the start of the action, taking into account existing results from former and other ongoing projects;

- Propose harmonised protocols and run material tests to measure the mechanical properties affected by the presence of hydrogen and critical for its integration into networks (should include e.g. crack propagation, fatigue, toughness, and impacts on welds and heat affected zones (HAZ)) and impact of chemical composition for grid components. The protocols should be made available to the public and should ensure that all results are comparable between the different testing laboratories involved. It should also, serve as a standardised reference guideline for future investigations.

Following the testing activities proposals should make available a database of gas grid metallic materials' behaviour in the presence of hydrogen associated with network operating conditions, assessing the compatibility of vintage and new gas pipes. There should also be a plan that ensures the that the database is updated after the project is finished with future testing results.

Projects should also identify acceptance criteria including the allowed size of defects, depending on the pressure and hydrogen concentration.

Proposals should ensure regular knowledge sharing with other topics devoted to hydrogen injection into gas grids that will require those tests' results, and especially HORIZON-JTI-CLEANH2-2022-02-02, HORIZON-JTI-CLEANH2-2022-05-03 and HORIZON-JTI-CLEANH2-2022-05-04.

At least two different research institutions should be included in the consortium in order to ensure the comparability of the testing results.

Proposals are expected to contribute towards the activities of Mission Innovation 2.0 - Clean Hydrogen Mission. Cooperation with entities from Clean Hydrogen Mission member countries, which are neither EU Member States nor Horizon Europe Associated countries, is encouraged (see section 2.2.6.8 International Cooperation).

TC2-03: Hydrogen and Hydrogen/Natural gas mixture leak detection system for continuous monitoring and safe operation of HRS and future Hydrogen/Natural gas mixture networks

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of around EUR 2.5 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 2.5 million
Type of Action	Research and Innovation Action
Technology Readiness Level	Activities are expected to start at TRL 3 and achieve TRL 5 by the end of the project See General Annex B.

Expected Outcome

The growing attention on methane emissions is also triggering a debate around the safety of hydrogen. Although different in nature, the two issues are frequently associated with each other in the public debate. During a recent event organised by the US-based Environmental Defence Fund, the topic of hydrogen leakage and related GHG emissions took up a prominent place in the discussion with members of the European Parliament and Commission officials. According to the participants, the discussion and the lessons learned about methane emission can be applied to the subject of hydrogen leakage. Even though hydrogen in itself is not a GHG, by depleting hydroxyl radicals (OH), thus increasing the atmospheric lifetime of methane as well as by influencing tropospheric ozone formation, the total GWP of hydrogen over 100 years can be estimated at 5.835. As hydrogen leakage, during storage and transportation, is potentially the largest source of anthropogenic hydrogen emissions, minimizing hydrogen leakage rates is therefore key to ensure climate sustainability of the developing hydrogen economy. Furthermore, as around 60% of hydrogen's global warming potential results from changes in methane concentration, tackling hydrogen leakage would be complementary to the EU Methane Strategy[36] and the Proposal for a Regulation to reduce Methane emissions of December 2021[37] as well as to the recent Global Methane Pledge[38]. As hydrogen has a very broad flammability range - a 4 percent to 74 percent concentration in air – leakage detection and prevention is also crucial from safety point of view, especially inside confined spaces.

Safety requirements of natural gas (NG), mixed NG/H_2 and pure hydrogen transport require robust yet innovative solutions for sensor-based leak detection monitoring throughout Europe. In addition, leaks at HRS level became one the main concerns to operate safely and economically the retail business.

The sensor technology development in this field should address the development, testing and validation of new detection techniques and tools for measurement by continuous

[35] https://www.geos.ed.ac.uk/~dstevens/publications/derwent_cc01.pdf
[36] https://ec.europa.eu/energy/sites/default/files/eu_methane_strategy.pdf
[37] https://eur-lex.europa.eu/resource.html?uri=cellar:06d0c90a-5d91-11ec-9c6c-01aa75ed71a1.0001.02/DOC_1&format=PDF
[38] https://www.globalmethanepledge.org/

monitoring of pure hydrogen and mixed methane-hydrogen emissions.

This will enable safer storage, transport (in NG Grid or trailers) and distribution of gaseous hydrogen. The approach to solve these safety issues may vary due to different demands at different sites, both enclosed and open air, and will depend on variable configuration of the network / distribution, different gas pressure ranges and hydrogen concentration, and possible interference from other components like the NG/H_2 mixture.

Current technologies for continuous leak detection monitoring are not satisfactory and should meet the industry & public area requirements.

Project results are expected to contribute to all of the following expected outcomes:

- The development of leak detection system that can classify leak types and leak sources according to risk, location, impact, consideration of severity, probability and predictability arising from sensors for leak detection and system integrity including predictive maintenance, odorised molecules and airborne technologies which will detect hydrogen leakage remotely (such as Raman LiDAR for hydrogen pipelines).
- To ensure safe operation of hydrogen infrastructure (e.g. HRS, filling centres, gas grids, compressor housings)
- Improvement of Leak detection time/rate and detection accuracy of the system
- Improvement in the productivity and cost effectiveness of the sensor device. While some leak categories may require continuous monitoring, for other leaks periodic measurements by mobile sensors or multiplexed arrangements may be more cost-effective. Continuous monitoring solutions can detect and report leaks in real-time and trigger early warning systems which helps to reduce risk for both humans and materials, especially in densely populated areas or densely built industry parks and refineries.

Project results are expected to contribute to all of the following objectives of the JU as reflected in the SRIA of the Clean Hydrogen JU:

- Increase the level of safety of hydrogen technologies and applications
- Enable through research and demonstration activities the transportation of hydrogen through the natural gas grid either by blending or via repurposing to 100% hydrogen.

The project is also expected to achieve the following technical KPIs:

- Concentration measurement accuracy for safe operation in terms of explosion limit, 1% lower explosive limit (LEL). This means that the sensor should be able to detect 0.04% of H2 in air;
- A minimum detection sensitivity of ± 0.18% by volume of hydrogen in air (a good practice is to set the detectors to alarm at 0.4% hydrogen by volume in air, which is 10% of the lower flammability limit (LFL);
- A maximum. response time of 1 sec at a concentration of 0.4% by volume (more than 10% LFL), while keeping in mind that sensor performance can vary from one application to another, this is extremely important for system designed to monitor hydrogen concentrations in rooms or areas (e.g. turbomachinery package enclosure) with high temperature environments in presence of hot surfaces with temperatures above auto-ignition (AIT).

Scope

The proposed research is expected to focus on developing and validating reliable leak sensing services and leak detection sensor technologies for hydrogen and NG/H_2 mixtures. The proposed research work should start at TRL 3 and end at TRL 5 or higher.

New and optimised leak detection sensors and tools should be developed in order to enable safer storage, transport and distribution of hydrogen. Leak detection technologies may include the development of new or optimization of existing portable and fixed sensors (ideally with remote access) with various technical approaches (e.g. acoustic, laser scanning, optical fibre sensors, infrared if NG/H_2 mix considered, odorised molecules, strain gauge). Optimisation of existing hydrogen emission detection systems in terms of measuring range, tolerance, temperature measuring range, pressure range, response and recovery time[39], and to lower the costs for investments, compression/operations and maintenance should also be considered.

Besides the technical KPIs that were already mentioned in the expected outcome section other key elements for leak detection monitoring are outlined below:

- Leak detection devices should identify the origin or the leak (e.g acoustic detection) to allow the commissioning & operating team to fix the issue;
- The leak detection system should warn personnel with visual and audible warnings when the environment is becoming unsafe; remote notification should be preferred.

The proposed technology should be suitable for continuous leak detection monitoring or/and periodic maintenance. Certain leak categories may be addressed by periodic measurement while other leak detection solutions may require interconnected mobile sensors or multiplexed arrangements.

Technologies related to hydrogen detection are based on the effects induced by the interaction of hydrogen with a selected sensing material. For example these effects can span catalytic, thermal conductivity, electrical and electrochemical, mechanical optical and acoustic properties. The scope of the topic is completely open to any kind of sensing technology.

Proposals are expected to contribute towards the activities of Mission Innovation 2.0 - Clean Hydrogen Mission. Cooperation with entities from Clean Hydrogen Mission member countries, which are neither EU Member States nor Horizon Europe Associated countries, is encouraged (see section 2.2.6.8 International Cooperation).

[39] Understood as time between two measurements.

TC2-04: Validation of a high-performance hydrogen liquefier prototype

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of around EUR 5 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 5 million.
Type of Action	Research and Innovation Action
Technology Readiness Level	Activities are expected to start at TRL 3 and achieve TRL 5 by the end of the project See General Annex B.

<u>*Expected Outcome*</u>

Hydrogen is liquefied by reducing its temperature to -253°C which increases its volumetric energy density (cryo-compressed form of hydrogen is recommended as well). This makes it possible to transport hydrogen and store it in large quantities enabling the transport of hydrogen by road/ship from centralised/decentralised production unit to customers or even direct use of liquid hydrogen for on-board storage in the frame of heavy-duty mobility.

Hydrogen liquefaction is an energy intensive process and current liquefaction plants rely on technologies and materials that need energy efficiency improvement and cost reduction to lower the overall hydrogen liquefaction cost and activate the LH_2 market at a competitive price in the near future.

Project results are expected to contribute to all of the following expected outcomes:

- Development an innovative hydrogen liquefaction sub-system (sub-modules, cycle or even equipment) that should:
    - Demonstrate technical and economic improvements with a potential for scaling-up
    - Be capable of reducing the energy consumption and specific cost of hydrogen liquefaction
- Prepare/initiate the massive deployment of liquid hydrogen for the benefit of heavy-duty transport with zero emission.
- Impact on a positive manner other hydrogen Europe Roadmaps related to liquid hydrogen (transportations, usages as aviation, HRS)

Project results are expected to contribute to all of the following objectives of the Clean Hydrogen JU SRIA:

- To increase the efficiency and reduce the costs of hydrogen liquefaction technologies.
- To contribute to the roll-out of next generation liquefaction technology to new bulk hydrogen production plants.

In terms of technical KPIs the project should aim at achieving the following:

- Reducing the H2 liquefaction energy intensity to 8-10kWh/kg H2
- Reducing H2 liquefaction cost to <1.5€/kg

Scope

A hydrogen liquefaction process is composed of the following main technological sub-systems: Pre-cooling, Cooling, Coldbox (Heat exchangers, ortho-para conversion), turbines and finally boil-off gas management.

There are currently various challenges associated to the production of low-cost liquid hydrogen:

- Only few developments working on optimising hydrogen cycles at a high TRL have been proposed;
- Current hydrogen energy consumption for liquefaction is around 10 to 12 kWh/kg equivalent to 35% of the hydrogen energy content on LHV vs power basis;
- Market development and cost strategies need to be developed for viable business models to promote LH2 product as an effective way of transporting hydrogen or eventually as a fuel;
- There are no uniform standards and safety regulations for liquid hydrogen.

To overcome the technological barriers of hydrogen liquefaction and to prepare a future massive industrial deployment at a high TRL, the high-performance hydrogen sub-system to be developed in proposals should address the following technical issues:

- An innovative concept different from what is used today. This can be focused at the system level or on one of the sub-system of a liquefaction unit;
- Construction of an industrial prototype at limited scale;
- Evaluate the performance, durability and efficiency of the prototype;
- Demonstrate the capability of the concept to be operated at lower load (in the range 50-100% of the nominal capacity) to be in line with future of renewable/low-carbon hydrogen production -e.g. by water electrolysis coupled with renewable electricity);
- Demonstrate according to the industrial prototype operation the H2 liquefaction energy intensity target between 8 - 10 kWh/kg considering feed hydrogen at 20 bar and 15 °C;
- The validated industrial prototype should prove and support the scalability of the innovative concept to suit flowrates above 100 TPD.
- TRL start of the project: 4 and TRL at the end of the project: 6

The proposed technology to be developed should be benchmarked against the technologies commercially available today based on the Helium Brayton Cycle and the Claude Cycle, both with externally supplied liquid inert nitrogen (LIN) for precooling on a small scale and should demonstrate a lower energy consumption.

Proposals should also address the following economic and regulatory issues:

- The innovative concept should demonstrate a specific liquefaction cost at around 1 to 2 €/kg for a small scale unit;
- The project should define a suitable roadmap to prepare the deployment of low carbon liquid hydrogen solutions;

- The project should address safety aspects of supplies of liquid hydrogen (infrastructure aspects);
- Propose accurate business models for the scale-up of the industrial phase for commercialisation purposes;
- Assess the various advantages of using renewable liquid hydrogen in heavy duty mobility in terms of emission reduction compared to tradition fuels including the boil-off management for the overall supply chain;
- Asses the various advantages of using renewable liquid hydrogen to valorise renewable energy used for the production of renewable hydrogen in an off-grid configuration;
- Contribute to the development of regulations, codes and standards needed for the LH2 safety issues;
- Define training requirements for operators in regards to LH2 safety operations.

Proposals are expected to address sustainability and circularity aspects.

TC2-05-A: Ammonia to Renewable Hydrogen: efficient system for ammonia cracking

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of around EUR 3.00 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 3.00 million.
Type of Action	Research and Innovation Action
Technology Readiness Level	Activities are expected to start at TRL 3 and achieve TRL 5 by the end of the project See General Annex B.

<u>Expected Outcome</u>

Liquid hydrogen carriers will play a significant role in diversifying Europe's energy supply corridor, transporting hydrogen at scale (>1,000 tonnes of hydrogen transported per day), especially across larger distances. Low carbon footprint, high energy density and easy storage and transportation are important key factors for their application. Amongst all liquid hydrogen carriers, ammonia has proven itself as a carbon free and sustainable candidate and, very importantly, it presents advantages of a one-way transport, in fact, ammonia does not need to be directly recovered and recycled after the dehydrogenation step (to release hydrogen). Moreover, even if safety and toxicity concerns have been raised, ammonia has been produced industrially for over 75 years, with a large existing infrastructure and offtake. However, further studies to assess the large-scale potential of ammonia as a hydrogen carrier are needed and energy efficiency and environmental impacts have to be carefully addressed.

Ammonia synthesis can be performed close to centralised hydrogen production sites, but their dehydrogenation needs to be easily obtained locally for different applications after transportation. Many technical and economic challenges related to dehydrogenation step and sustainability need to be overcome.

In order to bring ammonia cracking to the next stage of maturity project results are expected to contribute to all of the following outcomes:

- Contribute to Europe technology leadership developing innovative reactors and catalysts for the dehydrogenation of ammonia as well as new integrated solution for heat management and hydrogen separation and purification;
- Reducing the use of critical raw materials in ammonia dehydrogenation reaction;
- Improving the economics of the ammonia dehydrogenation process;
- Develop new business models related to the use of hydrogen from ammonia for various applications, such as centralised and distributed power generation, shipping, heavy mobility, etc;
- Contributing to the understanding of Europe need in terms of infrastructure and regulation for the management of liquid hydrogen carriers;
- Foster the demonstration of the solutions developed in the project throughout

Europe.

Project results are expected to contribute to all of the following objectives of the Clean Hydrogen JU SRIA: (especially for Pillar 2: Hydrogen storage and distribution – Sub Pillar: liquid H_2 carriers):

- Develop a range of hydrogen carriers that will be used commercially to transport and store hydrogen while improving their roundtrip efficiency and lowering their cost;
- Contribute to the SRIA KPIs on hydrogen carrier delivery cost, for 3000km ship transfer (Targets: 2024 = 2.5 €/kg, 2030 = <2€/kg);
- Contribute to the SRIA KPIs on hydrogen carrier specific energy consumption (Targets: 2024 = 17kWh input/kgH_2 recovered, 2030 = 12 kWh input/kgH_2 recovered). This figure encompasses the energy consumption for the production of ammonia from hydrogen, for which the project shall retrieve the value from the state of the art.

Scope

State of the art systems for H_2 recovery from ammonia require reaction units and catalysts operating at high temperatures (550-800°C) for complete ammonia conversion and are principally based on fired and heat transfer limited cracker design. The application of heat sources to deliver the required thermal energy is a restricting challenge for ammonia as a reliable Hydrogen carrier. Moreover, components thermal losses, power consumed by pumps, and loss of hydrogen due to imperfect recovery in conventional separation and purification section represent other important issues to address for the next generation ammonia dehydrogenation plants. In this regard, proposals should contain a set of principles applied in catalyst and reactor design, which can bring significant benefits in terms of process intensification and chain efficiency, lower capital and operating expenses, higher quality of products, less waste and improved process safety. Therefore, it is of interest to develop and demonstrate, at prototype scale, low-cost catalysts and integrated reactors that can deliver hydrogen at a high rate per volume from ammonia dehydrogenation at relatively low temperatures and high conversion so that zero-carbon pure hydrogen can be transported at long distances.

More in detail proposals should include:

- Development of catalyst (CRMs free catalysts or reduction of CRMs use should be considered) and reactor for the ammonia dehydrogenation at lower temperature compared to state of the art, capable to:
    - ensuring the highest possible ammonia conversion (>98%) reducing the downstream cleaning/recycling steps;
    - improving the overall thermal efficiency of the ammonia dehydrogenation step;
    - providing high reliability, ease of operation, and cost-effectiveness to hydrogen production.
- A demonstration system, running for at least 500 hours and producing at least 10 kg H_2/day at atmospheric pressure;
- Demonstration of hydrogen fuel quality (according to ISO 14687:2019) from dehydrogenation of the liquid hydrogen carrier in relevant conditions;
- Demonstration of Scalability of the developed system to large-scale production

(equivalent to the 100 tH_2/day) for long distance transportation;

- A Life Cycle Assessment of the developed system in the frame of the whole supply chain: ammonia inventory and make-up, (de)hydrogenation steps, temporary storage, shipping, CRM net consumption, etc;
- Techno-economic analysis for the scalability of the developed system to large-scale production for long distance transportation, i.e. 1000 t H_2/day, including centralised hydrogenation plant, storage, shipping and distributed dehydrogenation plants.

In order for the proposal to reach the expected outcome, the deliverables should be disseminated at the end of the proposal to the hydrogen mobility and hydrogen refuelling infrastructure sectors and relevant working groups of the standardisation technical committee's such as ISO TC 197, CEN TC 268, including the hydrogen purity standard ISO14687 and EN17124, related to hydrogen fuel sampling.

Proposals are expected to address sustainability and circularity aspects.

TC2-05-B: Efficient system for dehydrogenation of liquid organic hydrogen carriers

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of around EUR 3.00 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 3.00 million
Type of Action	Research and Innovation Action
Technology Readiness Level	Activities are expected to start at TRL 3 and achieve TRL 5 by the end of the project See General Annex B.

<u>*Expected Outcomes*</u>

Liquid hydrogen carriers will play a significant role in diversifying Europe's energy supply corridor, transporting hydrogen at large scale (>1,000 t H2/day) especially across longer distances. In this frame, liquid organic hydrogen carriers (LOHC) have attracted attention of Europe's research and industry community. LOHC provide the possibility of transporting significant amount of hydrogen during hydrogenation/dehydrogenation cycles. Availability and degradation issues should be further studied to assess the large-scale potential of these liquid carriers. In addition, energy efficiency and environmental impacts have to be carefully addressed.

The hydrogenation of LOHCs can be performed close to centralised hydrogen production sites, but their dehydrogenation needs to be easily obtained locally for different applications. Many technical, environmental and economic challenges related to dehydrogenation step need to be overcome.

Project results are expected to contribute to all of the following expected outcomes:

- Contribute to Europe technology leadership, developing innovative reactors and catalyst for the dehydrogenation of LOHC, including integrated solutions for heat management and hydrogen purification;
- Reducing the use of critical raw materials in LOHC dehydrogenation reaction;
- Develop affordable business models related to the use of hydrogen carried on by LOHC for various applications, such as centralised and distributed power generation, shipping, heavy mobility, etc;
- Contributing to the understanding of Europe need in terms of infrastructure and regulation for the management of liquid hydrogen carriers;
- Foster the demonstration of the solutions developed in the project throughout Europe;
- Contribute to the social acceptance of hydrogen technologies, demonstrating safe solutions for hydrogen transportation by LOHC.

Project results are expected to contribute to all of the following objectives of the Clean Hydrogen JU SRIA: (especially for Pillar 2: Hydrogen storage and distribution – Sub Pillar: liquid H_2 carriers):

- To continue the research on carrier cycling performance, chemistries, catalysis and reactors which show potential for improved roundtrip efficiency and life cycle assessment.
- Develop a range of hydrogen carriers that will be used commercially to transport and store hydrogen while improving their roundtrip efficiency and lowering their cost.
- Contribute to the SRIA KPIs on hydrogen carrier delivery cost, for 3000km ship transfer (Targets: 2024 = 2.5 €/kg, 2030 = <2€/kg);
- Contribute to the SRIA KPIs on hydrogen carrier specific energy consumption (Targets: 2024 = 17 kWh input/kgH_2 recovered, 2030 = 12 kWh input/kgH_2 recovered).

Scope

State of the art systems for H_2 recovery from LOHC require reaction units and catalysts operating at temperatures between 200 and 400 °C depending on the type of molecule. The application of heat sources to deliver the required thermal energy is a restricting challenge for selected organic liquids as a reliable hydrogen carrier. Moreover, components thermal losses, power consumed by pumps, and loss of hydrogen due to imperfect recovery in conventional separation and purification section represent other important issues to address for the next generation LOHC dehydrogenation plants.

The project should develop and demonstrate reactors and catalyst dedicated to the dehydrogenation of LOHC. In particular, the project should contain a set of principles applied in catalyst and reactor design, which can bring significant benefits in terms of process intensification and chain efficiency, lower capital and operating expenses, higher quality of products, less wastes and improved process safety. Therefore, it is of interest to develop and demonstrate, at prototype scale, low-cost catalysts and integrated reactors that can deliver hydrogen at a high rate per volume from LOHC dehydrogenation at relatively low temperatures and high conversion, so that zero-carbon pure hydrogen can be transported at long distances.

The proposal should contain:

- Development of catalyst (CRMs free catalyst or reducing of CRM use should be considered) for the LOHC dehydrogenation at lower temperature compared to the state of the art:
  - ensuring the highest possible dehydrogenation reaction conversion (>95%);
  - improving the overall thermal efficiency of the LOHC dehydrogenation step;
  - providing high reliability, ease of operation, and cost-effectiveness to hydrogen production;
  - an integrated system with high reliability, ease of operation, and cost-effectiveness to hydrogen production from LOHC.
- A fully CO_2-free dehydrogenation process;
- A demonstration system, running for at least 500 hours and producing at least 10 kg H2/day at atmospheric pressure;

- Demonstration of the absence of contaminants, by-products and degradation products from the dehydrogenation of LOHC in real conditions (hydrogen quality according to ISO 14687:2019);
- Demonstration of scalability of the developed system to large-scale production (equivalent to the 100 t H2/day) for long distance transportation;
- A Life Cycle Assessment of the developed system in the frame of the whole supply chain: LOHC inventory and make-up, (de)hydrogenation steps, temporary storage, shipping, CRM net consumption, etc;
- Techno-economic analysis for the scalability of the developed system to large-scale production for long distance transportation, i.e. 1000 t H2/day, including centralised hydrogenation plant, storage, shipping and distributed dehydrogenation plants.

In order for the proposal to reach the expected outcome, the deliverables are expected to be disseminated at the end of the action to the hydrogen mobility and hydrogen refuelling infrastructure sectors and relevant working groups of the standardisation technical committee’s such as ISO TC 197, CEN TC 268, including the hydrogen purity standard ISO14687 and EN17124, related to hydrogen fuel sampling.

Proposals are expected to address sustainability and circularity aspects.

TC2-07-A: Development of large scale LH2 containment for shipping

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of around EUR 6.5 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 6.5 million.
Type of Action	Research and Innovation Action
Technology Readiness Level	Activities are expected to start at TRL 2-3 and achieve TRL 5 by the end of the project See General Annex B.

<u>*Expected Outcome*</u>

An important element of the European Hydrogen strategy is to support liquid hydrogen(LH2) deployment for various usages and to allow the energy transportation over longer distances. A further important element of the Hydrogen strategy is to contribute to the cost decrease by importing energy from low-cost zones by development of an international hydrogen trade, and thereby also enabling import of hydrogen to the European Union. In the end this will lead to increase the EU's competitiveness, manufacturing capabilities and secure the energy supply.

Shipping of LH_2 will represent a flexible means for transport of larger quantities of hydrogen over longer distances, as well as for regional distribution without a gas-grid. LH_2 also represent a dense form suitable for fuel storage for energy demanding applications.

Project results are expected to contribute to all of the following expected outcomes:

- Enable safe, cost- and energy efficient transport of bulk LH_2. Large scale LH_2 ship storage concepts need to be developed for shipping of LH_2 at energy system scale, in the order of GW hydrogen energy flux. An important aspect is to utilise the techno-economic advantage of scale;
- Allow for the development of LH_2 containment for shipping exceeding the currently demonstrated size of about 1,250 m3, corresponding to 90 tonnes of hydrogen. At present, large-scale solutions for the storage and bulk transportation of liquid hydrogen are in their infancy. It is expected that the development will foster the basis for large scale trade of LH_2 by 2030 being a supplement and later an alternative to the current world-wide LNG trade;
- Design a scalable liquid hydrogen storage to large dimensions, in the range of those implemented for LNG shipping today, e.g. 200,000 m^3 per ship, distributed between a relevant numbers of storage tanks. Such a capacity will correspond to 14,000 tonnes of hydrogen transported per ship;
- Demonstration and first application of the developed liquid hydrogen storage technology may be at reduced scale

Project results are expected to contribute to all of the following objectives of the Clean Hydrogen JU SRIA:

- LH_2 containment tank capacity [tonnes]: 350 in 2024 and 2.800 in 2030
- Capex of installed LH_2 containment tank [€/kg]: 50 in 2024 and <10 in 2030
- LH_2 boil-off [%/day]: 0.5 in 2024 and <0.3 in 2030

Scope

The scope of this topic is to develop and validate containment concepts intended for the bulk shipping of liquid hydrogen. The concepts developed should also be suitable for a later scale-up.

Multiple European technology providers have started to design and develop LH_2 containment solutions, e.g. based on the IMO Type B, Type C and membrane tank designs currently available for LNG shipping, as well as for other novel concepts. Due to the considerably lower temperature of LH_2 than LNG, as well as the lower heat of vaporisation and different material compatibility characteristics, totally novel insulation concepts need to be developed if LH_2 should be contained with equally or lower boil-off rate as current LNG concepts.

The scope for the proposed project should include:

- Concept selection for large scale LH_2 containment to be used in shipping;
- Approval in Principle (AIP) for the LH_2 containment concept by one of the major IACS classification societies;
- Materials and component selection and integrity testing for LH_2 exposure, e.g. strength, ductility, toughness, thermal expansion, sloshing and compatibility;
- Sub-system testing for thermo-mechanical validation;
- Detailed design, construction, and testing of a scaled-down prototype of at least 10 t LH_2 capacity;
- General Approval for the LH2 containment system by one of the major IACS classification societies;
- Development of a preliminary integrated ship design with a corresponding cost estimation;

The topic could have potential synergies with the topic from ZEWT: HORIZON-CL5-2021-D5-01-07 “Enabling the safe and efficient on-board storage and integration within ships of large quantities of ammonia and hydrogen fuels”, but the targeted tank size in the present topic will most likely require a different conceptual approach.

Proposals are expected to address sustainability and circularity aspects.

TC2-08 Increased hydrogen capacity of GH 2 road trailers

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of around EUR 2.5 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 2.5 million.
Type of Action	Research and Innovation Action
Technology Readiness Level	Activities are expected to start at TRL 3 and achieve TRL 5 by the end of the project See General Annex B.

Expected Outcome

Due to its low volumetric density, hydrogen presents major challenges for transportation and distribution. Currently, compressed hydrogen transport faces limitations (mainly the delivery of small quantities of compressed hydrogen at low pressure) which inhibits its potential to become a widespread energy carrier. Moreover, the improvement and scale-up of transport and distribution technologies are needed for hydrogen to be transported efficiently, in high volumes, across large geographical areas. This topic aims to improve the efficiency of compressed hydrogen transport in order to achieve the optimum efficiency, taking into account the physical limitations.

The existing solutions operating at 500 bar have not yet reached the physical optimal efficiency and the optimum cost. Research and innovation should address this problem of increasing the mass of hydrogen transported during a transport. This objective can be reached by a significant increase in the operating pressure of the tubes employed in the transport while ensuring the safety of people and goods.

The amount of hydrogen transported with each trip defines the efficiency of compressed hydrogen transport. Increasing the amount transported by increasing volumetric capacity and/or pressure, therefore, has an impact on several parts of the logistic chain. Project results are expected to contribute to all of the following expected outcomes:

- Reduce the cost and the environmental footprint of transporting compressed hydrogen;
- Decreases the number of transport rotations between the site of production and the delivery site;
- Decreases the compressor size at the hydrogen refuelling station (HRS).

Project results are expected to contribute to all of the following objectives of the Clean Hydrogen JU SRIA:

- For the GH2 logistic: improve the cost and quantities transported;
- For the HRS capability: improve the delivered capacities and reduce the cost of the molecule at the nozzle by increasing the quantities available.

The efficiency of the solutions proposed should be evaluated with respect to the KPIs indicated below and taking into account the proposed short-term (2024) and long-term (2030) objectives proposed in the SRIA of the Clean Hydrogen JU.

- From a 350kg SoA @ 200 bar to some cases 850kg H2 @ 300b to 1300kg @ high Pressure in 2030;
- CAPEX/kg H2 payload should evolve from 600-650 in 2021 to 450 €/kg H_2 in 2024 and ultimately to >350 in 2030 with the high pressure;
- The goal by the end of the project would be to show a tube trailer with a payload of payload of 1.2 tonne and a capex of 400 €/kg H_2.

Other KPIs to be reached by the end of the project are:

- Operating pressure: above 500 bar;
- Tubes gravimetric capacity 5-5.3%;
- Minimum cylinder/tube retest period 5 year.

Scope

As mentioned above, the improvement of compressed hydrogen transport requires a technical improvement that also takes into account financial, regulatory and normative aspects. Commercial solution starts to exist on the market in particular for pressure at 500 bar. The challenge is to go to higher pressure at a very significant lower cost.

The scope of this topic is to develop and validate a solution with a minimum payload of 1.2 tonne of compressed hydrogen above 500 bar by end of the project. The solution should be cost competitive compared to existing solutions reaching at least a cost of 600-650 €/kg of hydrogen.

Proposals should investigate the following aspects:

Technical aspects

There are several parameters to take into account. The increase in the transport efficiency is directly linked to the increase in the operating pressure and the decrease of the tube weight, which will allow a significant improvement in the mass per unit of compressed hydrogen transported. Existing transport solutions use an operating pressure (service pressure) of 200 bar. Solutions with higher pressure start to be available. The final objective is to reach an operating pressure of 700 bar by 2030.

At constant volume, the increase in operating pressure increases the mass of hydrogen contained in each gas tube. But, with no improvements in the tubes design and materials efficiency, increasing the pressure will significantly increase the weight of the tubes containing hydrogen. This will increase the lorry fuel consumption and the transport cost and environmental footprint. In addition, in compliance with EU regulation, the authorised transport weight in a trailer is limited. Therefore, new solutions, based on new competitive materials or concepts, are needed to achieve the target of 1,500 kg H2 tube trailer payload at operating pressure 700 bar by 2030, such as but not limited to:

- New lighter tubes manufactured with/without liners of improved performance materials (high strength alloyed steel, stainless steel or polymeric material) in combination with improved reinforcement (composite), in order to increase the pressure conditions, reducing the weight of the tube and assuring the requested safety levels and durability, with affordable manufacturing costs;

- The deployment of a new design of high-pressure cylinder based on regulatory / normative documents (as per example EN 17339 that allows composite tubes with reduced safety factor);
- Large diameter composite tubes;
- More efficient filament winding and components such as valves, etc.

Applicants should propose new solutions to decrease the specific weight (e.g. per unit of hydrogen transported) of the package.

All proposed solutions should take into account the safety of the peoples and goods. The proposal should describe the method that the applicant will apply to take into account the safety aspects for the transportation system (trailer, container, bundle), tube, frames, pressure relief system (e.g. risk assessment), etc.

<u>Financial aspect</u>

The proposed solutions should be innovative in terms of capital expenditure. That aspect may be addressed by using, innovative design, cost-effective materials, competitive manufacturing techniques, innovative organisation, etc.

The proposals may should also address the Total Cost of Ownership (TCO).

<u>Regulatory and normative aspect</u>

In order to protect the people and goods, the design, manufacturing and use of compressed gas solutions are heavily regulated by international (e.g. RID/ADR), EU (e.g. TPED) regulations and ISO (International Standard Organisation) and CEN (European Committee for standardisation) standards. Technical innovative solutions may not be covered by existing standards and regulations.

The applicant should identify if the proposed solutions are covered by existing standards and/or regulations. A maximal hazard potential and its likelihood should be taken into account. If gaps are identified, the proposal should list these gaps and indicate the relevant activities that should be performed to fill these gaps.

The applicant should include actions to monitor regulatory developments and as necessary and relevant, participate in working groups working on this topic.

TC2-10: Development of novel or hybrid concepts for reliable, high capacity and energy-efficient H2 compression systems at real-world scale

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of around EUR 5.00 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 5.00 million
Type of Action	Innovation Action
Technology Readiness Level	Activities are expected to achieve TRL 7 by the end of the project See General Annex B.
Admissibility conditions	The conditions are described in General Annex A. The following exceptions apply: The page limit of the application is 70 pages.
Eligibility conditions	The conditions are described in General Annex A. The following exceptions apply: At least one partner in the consortium must be a member of either Hydrogen Europe or Hydrogen Europe Research.
Legal and financial set-up of the Grant Agreements	The rules are described in General Annex G. The following exceptions apply: Purchases of equipment, infrastructure or other assets used for the action must be declared as depreciation costs. However, for the following equipment, infrastructure or other assets purchased specifically for the action (or developed as part of the action tasks): compression prototype/s and related components, costs may exceptionally be declared as full capitalised costs.

<u>*Expected Outcome*</u>

Interest for hydrogen as an energy carrier is growing and receiving support in different sectors at an unprecedented rate. Many use-cases for low carbon hydrogen solutions are currently being investigated and include mobility, industrial processes & back-up power. Power-to-gas plants and hydrogen injection into new or pre-existing gas pipeline networks are some of the production and distribution options being developed.

Today, sustainable hydrogen production technologies (e.g. electrolysers, biomass pyrolysis, etc) can only achieve low outlet pressures of 30 bar or less. As a result, a compression step is necessary before gaseous hydrogen can be stored and distributed, as trailer, requiring specific refilling centre.

Hydrogen compression is one of the obstacles to achieving an economical and energy-efficient hydrogen infrastructure. Several mechanical compressor technologies exist but their performances (in terms of CAPEX, OPEX, maintenance, electricity consumption and noise) are insufficient. Innovative, non-mechanical compression technologies have been developed in previous FCH JU projects[40] (PHAEDRUS, Don Quichote, H2Ref, COSMHYC, COSMHYC XL, COSMHYC DEMO) over the past few years and have increased in TRL. However, in order to satisfy the ever increasing and evolving demand for hydrogen as a decarbonisation strategy, the different compression concepts need to be further developed and their ability to meet a wider range of use cases needs to be demonstrated under real operating conditions. In particular, these technologies should demonstrate an improved efficiency compared to mechanical compressors, a higher reliability resulting in lower maintenance costs, a strong flexibility to compress hydrogen from different sources with different profiles (purity, flow rates, pressure levels), and be appropriate to be installed in noise-sensitive environments.

Project results are expected to contribute to all of the following expected outcomes:

- Contributions to at least 1 full scale demonstrator for hydrogen mobility or industrial use of hydrogen by 2025;
- Contributing to keep European leadership in the hydrogen infrastructure solutions, based on compression technologies that will be applicable for hydrogen mobility, power-to-gas and industrial use of hydrogen (as refilling centre);
- Breakthrough and game changing technologies for hydrogen compression will be fully demonstrated by 2026;
- Foster the replication of the solutions demonstrated in the project in at least 5 additional locations by 2028;
- Strengthening the European value chain on hydrogen infrastructure by supporting the development of new EU industrial companies (incl. SMEs) active in innovative compression technologies;
- Lowering the costs of production of renewable hydrogen, thus accelerating the expansion of a hydrogen-based infrastructure (for which hydrogen compression is a key element).

Project results are expected to contribute to all of the following objectives of the Clean Hydrogen JU SRIA:

- To develop more efficient compressor technologies;
- To reduce the total cost of ownership of compression and purification technologies;
- To increase the reliability and lifetime of compression and purification technologies.

H2 compression optimization as a result of the project will contribute to strengthening the business model for renewable hydrogen production from sustainable technologies (such as water electrolysis via renewable energies), thus further supporting the decarbonisation of the energy sector. Hydrogen distribution methods, such as road transport and hydrogen injection into the gas grid will also greatly benefit from the project, supporting the expansion of the hydrogen refuelling station network in Europe in all sectors of hydrogen mobility (light duty, heavy duty, trains, ships, etc), thanks to increased reliability and cost-efficiency of the compression bottleneck.

The following KPI's should be reached at the end of the project:

- Technical lifetime: Feasibility of achieving 20 years lifetime for the compression solution in the mid-term;

[40] https://www.clean-hydrogen.europa.eu/projects-repository_en

- MTBF: 10,000 hours in the short term, with a perspective for 25,000 hours in the long-term (for example by extrapolation and using accelerated tests in the demonstration phase, inherent reliability of chosen components, etc);
- Final pressure target depending by application:
  - Filling Centres: range (300-700) bar
  - HRS: 350-700 bar
  - Pipeline for pure GH_2 or blended gas: above 90bar
- Electricity consumption lower than 4 kWh/kg immediately and lower than 3.2 kWh/kg in the mid-term, starting by a hydrogen source at 10 bar, or demonstrating it;
- Maintenance costs of 0.1 €/kg immediately, with perspective to achieve 0.03 €/kg in the long term;
- CAPEX of 1,200 €/(kg H_2/day) for demonstration system and prove cost reduction up to 600 €/(kg H_2/day) when produced in large series.

Scope

Experience and lessons learnt from hydrogen demonstration projects over the past years clearly point to hydrogen compressors as one of the most critical components in terms of costs, performance and reliability. As one of the core components of most hydrogen installations, improving the state of the art of compressors is of high importance for the future success of hydrogen landscapes.

Several projects[41] have successfully shown the potential of different novel compression technologies and first prototypes have been commissioned and operated at limited scale (4 kg/h in COSMHYC, 8 kg/h in COSMHYC DEMO). There is now a need to scale-up the technologies to >1 t/day to meet the requirements of emerging use cases, incl. gas grid injection, HRS for heavy mobility and distribution supply chain (refilling centre). In addition, while previous projects focused on use cases with limited constraints on the hydrogen source (very high purity, stable supply pressure and flow rate), there is a need to increase the robustness and flexibility of new compression technologies to adapt to a broader range of hydrogen sources with varying gas quality to decrease costs and improve reliability in an industrial context

This topic aims to further develop innovative compression concepts, helping them reach the necessary maturity for large scale deployment. It involves developing, scaling-up, building, installing and testing a compression prototype at a client site with real-life applications (e.g. a hydrogen refuelling station, hydrogen production from renewable energies coupled with a filling centre, gas grid injection) and at a representative scale:

- Filling Centres: 4-20 tonnes/day;
- HRS: 0.5-4 tonnes/day;
- Pipeline for pure GH2 or blended gas: 1-10 tonnes/hr.

It should consist of either an innovative compression solution, or a combination of different solutions including at least one innovative technology. The solution should demonstrate high

[41] https://www.clean-hydrogen.europa.eu/projects-repository_en

levels of availability and efficiency, with low costs, low maintenance requirements, and high operational safety.

The demonstration duration should be at least one year of one compression solution at representative scale in a real commercial use case (gas grid injection, mobility, filling centre or a combination of uses) with an availability of at least 95%. In addition, the compression concept's potential regarding scalability, industrialisation and commercialisation at mass production scale should be proven.

The technology should demonstrate to be well-adapted to a wide range of hydrogen-based applications in all parts of the value chain. In addition, the concept should show its ability to be directly connected to a renewable hydrogen source without the need for further compression steps, and to scale-up above capacity in the mid-term, above reported.

The scope of the project should include the development, manufacturing, installation, and operation of the innovative hydrogen compressor, as well as the necessary resources for measuring, monitoring, treating and interpreting data for a techno-economic analysis throughout the project. The durability of the solution should be shown using specific accelerated stress tests, highlighting a low degradation rate and high reliability.

Proposals should identify a demonstration site and end-users where the compression technology will be applied. A limited share of the funding may be allocated to the costs induced by the surrounding infrastructure to which the compression solution will belong and contribute, including studies, civil engineering, and other equipment (such as HRS, filling centre or gas grid injection facility).

This topic is expected to contribute to EU competitiveness and industrial leadership by supporting a European value chain for hydrogen and fuel cell systems and components.

It is expected that Guarantees of origin (GOs) will be used to prove the renewable character of the hydrogen that is used. In this respect consortium may seek out the purchase and subsequent cancellation of GOs from the relevant Member State issuing body and if that is not yet available the consortium may proceed with the purchase and cancellation of non-governmental certificates (e.g CertifHy[42]).

Proposals should provide a preliminary draft on 'hydrogen safety planning and management' at the project level, which will be further updated during project implementation.

[42] https://www.certifhy.eu/

TC2-12: Sampling methodology and quality assessment of HRS

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of around EUR 4 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 4 million
Type of Action	Research and Innovation Action
Technology Readiness Level	Activities are expected to start at TRL 3 and achieve TRL 5 by the end of the project See General Annex B.
Legal and financial set-up of the Grant Agreements	The rules are described in General Annex G. The following exceptions apply: Beneficiaries must, up to 4 years after the end of the action, inform the granting authority if the results could reasonably be expected to contribute to European or international standards.

<u>*Expected Outcome*</u>

In order to contribute to the 2030 Climate plan, the 'Fit for 55' climate action plan and Green Deal, it is of the utmost importance that the quality of hydrogen fuel dispensed at the Hydrogen Refuelling Station (HRS) is meeting the applicable requirements (Directive on Alternative Fuels Infrastructure, Directive 2014/94/EU[43] and proposal for a regulation on the deployment of alternative fuels infrastructure 2021/0223(COD)[44] and standards EN17124:2018 & ISO14687:2019. The presence of impurities will cause Fuel Cell (FC) degradation and will dramatically impact the FC durability of the zero emission Fuel Cell Electrical Vehicles (FCEV's). This will have detrimental effects on customer satisfaction and competitiveness of the FC technology, jeopardising the establishment of the hydrogen society.

To secure the dispensing of H2 up to quality standard, significant measures from production up to HRS nozzle should be taken. In addition, a hydrogen quality assurance plan guaranteeing the quality at the nozzle should be in place. These requirements are directly affecting the hydrogen price. EN17124:2018 is describing two possible hydrogen quality assurance methodologies: a prescriptive approach and a Risk Assessment (RA) based approach. It is the current industry consensus that the RA approach is the most cost effective one, but it cannot be applied as the required Occurrence Class for each impurity is not clarified in the EU market (as described in ISO19880-8:2019 & EN17124:2018). In addition, the existing EU hydrogen quality laboratories still need to be fully validated according to ISO21087:2019 for real market application. Furthermore, in case an HRS is dispensing impure hydrogen, the station should be closed for maintenance until the problem

[43] https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A32014L0094

[44] https://ec.europa.eu/info/sites/default/files/revision_of_the_directive_on_deployment_of_the_alternative_fuels_infrastructure_with_annex_0.pdf

is solved; a procedure that has long been established in detail for conventional fuels. In conclusion, the hydrogen quality management directly impacts the hydrogen price as well as the availability of the refuelling stations and consequently are affecting the Clean Hydrogen for Europe JU objectives.

Project results are expected to contribute to all of the following expected outcomes:

- Widespread utilisation of the cost effective hydrogen quality assurance system by HRS operators based on RA as described in ISO19880-8:2019 & EN17124:2018 enabled by the developed Occurrence Class statistically representing the EU market (by 300 samples during the project);
- EU based hydrogen quality assurance infrastructure, including an operational network of at least 5 laboratories with market-proven capability confirmed through regular proficiency testing to the required standards;
- Alignment and standardisation of the hydrogen quality sampling and analysis at the nozzle of EU HRS, including an interoperable methodology and approach for 350 & 700 bar sampling;
- Guided future research efforts in the field of hydrogen quality (e.g. online analysers, sensors) based on the established open source database of hydrogen impurity occurrence representative to the EU market.

Project results are expected to contribute to all of the following objectives of the Clean Hydrogen JU SRIA: (Pillar 2: Hydrogen storage and distribution - Hydrogen refuelling stations):

- To support the availability of heavy-duty Hydrogen Refuelling Stations:
  - 98% of HRS availability for 350 & 700 bar stations;
  - Mean time between failures of 144 and 72 days for 350 & 700 bar stations respectively.
- To support the creation of a network of Heavy-duty Hydrogen Refuelling Stations across Europe while contributing to the decrease of the total cost of ownership of Hydrogen Refuelling stations by more than 50%:
  - decrease of HRS contribution in the hydrogen price to €2 and €3 per kg for 350 & 700 bar stations respectively;
  - achievement of total cost of ownership (TCO) of €10 and €6 per kg for Light Duty and Heavy-Duty FCEV respectively.

Scope

The HyCoRa and HYDRAITE FCH JU funded projects[45] focussed on the impact of hydrogen impurities on the FC (in particular to assess the severity level) and conducted a limited sampling effort, resulting in about 48 samples taken and analysed from the market over a period of about 6 years. The outcome was that not all HRS are conform to the existing quality standards; in addition, this amount of publicly accessible data is too limited to be representative to the occurrence of impurities in the EU market. Such information is required in order to enable the cost-efficient RA quality assurance approach (requiring the Occurrence Class next to Severity Level as described in EN17124:2018). The Euramet

[45] https://www.clean-hydrogen.europa.eu/projects-repository_en

MetroHyVe[46] project developed sampling and hydrogen quality analysis methodologies on laboratory scale that need still to be validated for real market application. In addition, an initial effort in hydrogen purity laboratory proficiency testing was conducted; 4 impurities (H2S, CO, N2 & H2O) were evaluated by 13 global laboratories, showing significant differences between laboratory results. Thereof, a regular continuation of the inter-laboratory comparison for the entire list of contaminants stipulated by the technical standards is required.

Following actions need to be tackled in order to address the expected outcomes successfully:

- Clarification of the Occurrence Class of the impurities in the EU market (as stipulated in ISO19880-8:2019 & EN17124:2018 (Table 2 – Occurrence Classes for each impurity)), to enable the RA approach for hydrogen quality assurance. The number of samples acting as a base to define the Occurrence Class is described in action number 3, stated below. Next to the hydrogen quality samples, all required HRS specifics to allow the utilisation of this information as an input for the Occurrence Class of the HRS quality RA should be collected. These will be defined based on input obtained from at least 5 relevant stakeholders such as gas & technology suppliers and HRS operators;
- Validate the capability of at least 5 EU based hydrogen purity laboratories, for both sampling as well as analysing hydrogen according to the applicable standards ISO19880-1:2020, ISO19880-8:2019, EN17124:2018 and ISO21087:2019, or their respective revisions. Validity of the utilised techniques should be evidenced by mass market investigation of the EU hydrogen quality as stipulated in action number 3, stated below. Next, proficiency testing up to standard level should be regularly conducted and has to be an integral part of the activity. The proficiency results should be made publicly available in an anonymised way. Root cause analysis should be conducted in case of diverging test results and countermeasures should be developed. Utilisation of technologies and methodologies researched in past funded projects (see above) is expected and support from the EU metrological network is recommended;
- As a prerequisite to support activity 1 & 2, and to make the information available for future learnings, a publicly accessible hydrogen quality database representing the hydrogen quality supplied in the EU should be established. In order to get a representative and statistical overview of the hydrogen quality dispensed at 350 & 700 bar stations in the EU market, at least 100 samples from the HRSs should be collected and analysed per year, of which maximum 25% of the samples are obtained from the same HRS. The utilized methodologies' interoperability should be maximized to be applicable on different pressures (350 & 700 bar). The location of samples taken will be in proportion to the geographically spread of HRSs across the EU. In addition, the occurrence of at least 4 impurities beyond EN17124:2018 and ISO21087:2019: i.e. new non-standardised impurities or not well-defined impurities such as 'total' sulphur or halogenated compounds of a selected number of samples should be investigated by utilisation of wide scope analytical techniques.
- Based on the output of objectives 1, 2 and 3, a working group should clarify the

[46] https://www.euramet.org/research-innovation/search-research-projects/details/project/metrology-for-hydrogen-vehicles/?tx_eurametctcp_project%5Baction%5D=show&tx_eurametctcp_project%5Bcontroller%5D=Project&cHash=306d1f42e20989c0b2658abf0f76c8ca

development need or improvement opportunities in the field of hydrogen quality assurance. In addition, recommendations to support the development of the future HRS sampling standard (ISO19880-9, TC197) should be made.

As the scope of the topic contains significant portions of measurement and analysis, cooperation with the European metrology community, such as the European Metrology Network for Energy Gases[47] of Euramet, should be pursued. Within this context proposals should explain how they would complement and avoid overlaps with the ongoing activities of Euramet, e.g. project MetroHyVe2[48].

In order for the proposal to reach the expected outcome, the deliverables should be disseminated at the end of the proposal to the hydrogen mobility and hydrogen refuelling infrastructure communities and relevant working groups of the standardisation technical committee's such as ISO TC 197, ISO TC 158 & CEN TC 268, including the new standard under development ISO19880-9 (TC 197), related to HRS sampling. Proposals are encouraged to include a formal standardisation body within the consortium.

Proposals are expected to contribute towards the activities of Mission Innovation 2.0 - Clean Hydrogen Mission. Cooperation with entities from Clean Hydrogen Mission member countries, which are neither EU Member States nor Horizon Europe Associated countries, is encouraged (see section 2.2.6.8 International Cooperation).

[47] https://www.euramet.org/european-metrology-networks/energy-gases/what-we-do/

[48] https://www.euramet.org/research-innovation/search-research-projects/details/project/metrology-for-hydrogen-vehicles-2/?L=0&tx_eurametctcp_project%5Baction%5D=show&tx_eurametctcp_project%5Bcontroller%5D=Project&cHash=9875d9a3fb9cfbdf8e44d44e12ac5eea

TC2-13: Implementing new/optimised refuelling protocols and components for high flow HRS

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of around EUR 4.00 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 8.00 million
Type of Action	Research and Innovation Action
Technology Readiness Level	Activities are expected to start at TRL 3 and achieve TRL 6 by the end of the project. See General Annex B.
Procedure	The procedure is described in General Annex F. The following exceptions apply: To ensure a balanced portfolio covering complementary approaches , grants will be awarded to applications not only in order of ranking but at least also to one additional project that is / are complementary, provided that the applications attain all thresholds.

<u>*Expected Outcome*</u>

The development of hydrogen powered heavy duty vehicles (HDV) is key to be able to decarbonise transport of passengers and goods. To achieve this effectively, hydrogen refuelling station (HRS) technologies need to be upgraded to address the refuelling needs of heavy-duty vehicles. The actions described herein will contribute to bring appropriate HDV HRS and HDV HRS components on the market.

Project results are expected to contribute to all of the following expected outcomes:

- Fully developed and ready to commercialise HRS components (nozzle, hose, cooling unit, safety critical devices, pressure regulator or flow control valve, filters, advanced safety-related communication interface, flow meter etc) meeting the refuelling needs of HDV;
- Certification of the above-mentioned components according to relevant ISO, OIML or CEN standards. If related standard is still under development, contribution to standard writing in order to ensure components compatibility with future and enable certification in the short term;
- Demonstration of the fully integrated chain of specific HDV HRS components on at least 2 different HDV HRS for a total of 300 refuelling events each;
- Full demonstration of new standardised refuelling protocols for heavy duty vehicle developed in ISO TC 197 WG24 or other standardisation body, as well as approval concept for the conformity of the station to the protocol.

Project results are expected to contribute to all of the following objectives of the Clean Hydrogen JU SRIA (Pillar 2: Hydrogen storage and distribution – Sub-pillar Hydrogen Refuelling Stations:

- To tackle the technical challenges associated with heavy-duty hydrogen refuelling stations in order to develop a commercial solution that conforms to the heavy-duty requirements;
- To increase the reliability and availability of Hydrogen Refuelling Stations;
- To support the creation of a network of Heavy-duty HRS across Europe.

In particular projects results are expected to contribute to the attainment by 2024 of the relevant KPIs identified in the SRIA of the Clean Hydrogen JU including:

- HRS mean time between failures: 72 hours (700 bar) and 144 hours (350 bar);
- Annual maintenance cost: 0.5 €/kg (700 bar) and 0.35 €/kg (350 bar);
- HRS CAPEX(200 – 1000 kg/d): 1,5- 4 k€ / (kg/Day) @ 700 bar and 0.65-2.5 0.35 k€ / (kg/Day) @ 350 bar;

In order to contribute to these KPI, the following additional KPI should be targeted:

- The target price for the complete refuelling line downstream compressor and storage should be 300 k€ with following components target price for 50-100 unit/year: Nozzle 6 k€; Hose 2 k€; Advanced bidirectional communication interface: 2k€; Break away: 2.5 k€; Flow measuring device: 25 k€; Cooling system: 200 k€; Pressure regulator or flow control valve: 6 k€.

Scope

To fulfil future HDV refuelling needs such as fuelling a 100 kg HD truck storage system in 10 minutes, an HDV refuelling point should reach a mean fuelling rate of approximatively 170 g/s with a peak fuelling rate up to 300 g/s. To guarantee optimal refuelling performances, reliabilities and costs for a wide range of possible HDV storage capacities and configurations, new fuelling protocols based on advanced and safe communication between vehicle and station (e.g. the one developed in ISO TC 197 WG24 based notably on feedback from PRHYDE project[49]) should be implemented. To meet these requirements, proposals should develop, test and certify appropriate components to bring them to commercialisation.

Proposals should address:

- Qualification of the components:
  - Identify the gaps in terms of standards, market availability and testing;
  - Perform a qualification roadmap individual for each component, with specific targets;
  - At the end of the project, identify potential missing gaps, components, experience to be continued before full market implementation.
- Qualification of the protocol:
  - Implement the components developed in the qualification program or potential alternatives
  - Define a refueling protocol validation roadmap, accounting for available standards
  - Check that each component performs as expected in a full assembly

[49] https://www.clean-hydrogen.europa.eu/projects-repository_en

- Validate the protocol on various testing
- Dissemination of the outcomes;

During the project, those of the following components that are not available on the market should be developed, tested, certified and brought to commercialisation:

- Nozzle, break away and hose: H70 and H35 very high flow nozzle, break away and hose should be designed for 300 g/s peak flow. A particular attention should be paid to limit pressure drop and heat transfer from the surrounding atmosphere. The project should contribute from the beginning of the project to ISO TC 197/WG5 and WG22 currently working on a new version of ISO 17268 and ISO 19880-5. The components developed should be certified according to previously mentioned standard if published before the end of the project. The feedback on current components drawbacks (size, weight and manoeuvrability, freezing preventing disconnection of nozzle at the end of the refuelling, fragility when dropped, life duration) should be considered.
- Advanced bidirectional communication interface (HRS and vehicle side): Optimised refuelling protocol able to address a wide range of on-board storage systems and configurations will need an advanced communication interface between vehicles and stations, sufficiently reliable to allow communicated data to be used for safety critical decision in the refuelling protocol. The interface should be developed in collaboration with major European HDV manufacturers. The project should contribute as soon as possible to ISO TC 197 WG24 Task force 2 working on ISO 19885-2 standard on the definition of communications between the vehicle and dispenser control systems.
- Flow measuring device: The project should develop a flow meter compatible with high flow rate (170 g/s mean flow rate, 300 g/s peak flow, targeting >100kg total mass per refuelling) for H35 and H70. An entire measuring device (including flow meter, calculator etc) ready to be implemented on a dispenser should be developed and certified according to OIML R139.
- Cooling system: The cooling system should be able to cool hydrogen to obtain a hydrogen temperature at the dispenser of -20°C or below, for a mean fuelling rate of 170 g/s with peak flow of 300 g/s. During design phase the balance between refuelling performance versus the cost (CAPEX and OPEX) of the cooling system should be studied. Particular attention should be paid to reducing the footprint
- Pressure Regulator or Flow Control Valve: The component should be able to control the pressure ramp rate or the flow appropriately to follow new refuelling protocols and manage corresponding range of flow/pressure variations. A focus should be paid to reaching the needed reliability of valves.
- Safety critical devices, valve, filter and other components: The project may develop any specific components of the refuelling line downstream compressor and storage that is not available on the market with characteristic suitable for HDV refuelling. Particular attention should be paid to reach sufficient flow coefficient to limit pressure drop throughout the whole system. Special focus should be paid to reach high reliability throughout the fuelling system. Development of efficient and long-life filters to keep contamination and wear to a minimum will be necessary and investigated as during the project.

- Dispenser: Most of the above-mentioned component should be integrated in a dispenser that should follow ISO 19880-2. The project should also pay attention to propose standardised integration and sizes of the dispenser in a logic of one fit all.

The targeted rated pressure of the developed components should be at least 138% of the nominal working pressure following the recommendation of chapter 8 of ISO 19880-1. The component shall be developed within the first 2.5 years of the project to allow 1.5 years for integration and testing in a full refuelling line assembly.

During the project, a fully integrated component chain from pressure regulator to nozzle and associated control command should be designed and built and should be integrated on at least two HRS having storage and/or compression capability allowing several 100 kg HDV onboard storage per day. A testing phase of at least 6 months under relevant operating conditions should take place during the project. Full experimental set up details and experimental data of the tests should be made publicly accessible at the end of the project.

HRS architecture may be based on direct compression or transfer from high-pressure cascade storage, but these components (compressor and storage) are not the focus of the scope of this action and only a minor share of project funding should be related to storage, compressor and further station adaptations. The control command of these HRS should integrate new HDV refuelling protocols currently under development in ISO TC 197 WG24 or other standardisation bodies. The project should take part as soon as possible to ISO TC 197 WG24 task force 3 working on ISO 19885-3 technical document on new high flow refuelling protocols to better understand these protocols and contribute with feedback on implementation challenges. This project should benefit from the work previously carried out by the PRHYDE[50] project on HDV refuelling protocols.

The project should assess hazard and associated risk of refuelling with the developed fuelling line and should benefit from, but also provide added value compared to the work previously carried out by the MultHyFuel[51] project on the safety considerations for the HRS design.

Applicants are encouraged to involve component manufacturers, HRS manufacturers, HRS operators and heavy-duty vehicle manufacturers.

[50] https://www.clean-hydrogen.europa.eu/projects-repository_en
[51] https://www.clean-hydrogen.europa.eu/projects-repository_en

TC3-08: Development and demonstration of mobile and stationary compressed hydrogen refuelling solutions for application in inland shipping and short-distance maritime operations

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of around EUR 7.00 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 7.00 million.
Type of Action	Innovation Action
Technology Readiness Level	Activities are expected to start at TRL 3 and achieve TRL 6 by the end of the project. See General Annex B.
Admissibility conditions	The conditions are described in General Annex A. The following exceptions apply: The page limit of the application is 70 pages.
Legal and financial set-up of the Grant Agreements	The rules are described in General Annex G. The following exceptions apply: Purchases of equipment, infrastructure or other assets used for the action must be declared as depreciation costs. However, for the following equipment, infrastructure or other assets purchased specifically for the action (or developed as part of the action tasks): bunkering prototype/s and related components, costs may exceptionally be declared as full capitalised costs.

Expected Outcome

Hydrogen and hydrogen derivative fuels are expected to play a vital role in enabling the decarbonisation of shipping and maritime activities. Many projects are underway seeking to develop hydrogen fuel cell systems to provide both auxiliary and propulsive power for vessels at a range of scales, with strong engagement from ship designers, ship builders, owners and operators, as well as fuel cell developers. However, these organisations may not be well placed to develop the understanding of technical and societal parts of bunkering infrastructure deployment required to facilitate market uptake of hydrogen-fuelled solutions. This action will address that gap.

This topic aims to contribute to setting standards for future inherently safer hydrogen bunkering for inland shipping, and for short-distance sea-going maritime applications, including in island contexts. Developing these solutions is of vital importance to facilitating further innovation activity in deploying hydrogen solutions in shipping, as well as in de-risking future investments.

Project results are expected to contribute to, but not limited to, the following expected outcomes:

- Improved understanding of the health and safety requirements for hydrogen bunkering in a range of operational shipping contexts, which will make bunkering more efficient and inherently safer to reduce hazards and consequences of potential incidents, and thus de-risk future developments;

- Closed knowledge gaps on characteristic hazards and associated risks;
- Lessons learned which can inform heavy duty refuelling development for other sectors, to facilitate further deployment of hydrogen in a wide range of transport and freight sectors;
- Identification of regulatory challenges and barriers, and areas of focus for pre-normative research and regulatory reform, in order to unlock future fuelling of heavy-duty applications;
- Guidelines and/or draft standards for hydrogen bunkering components and systems to increase the coherence of innovation activities and improve uptake throughout Europe and beyond;
- Leveraging the opportunities associated with shipping as an off-take sector in the development of business cases for hydrogen storage and distribution networks.
- Improved understanding of requirements for type approval for both ship-to-shore and ship-to-ship interfaces and control systems to facilitate widespread commercialisation of the solutions;
- Deployment of hydrogen bunkering infrastructure of at least 800 kg H_2/day capacity in project locations;
- A boost in the uptake of hydrogen-fuelled vessels, and associated commercialisation benefits for the broader hydrogen economy;
- Training for vessel crew and bunker terminal personnel, which can be replicated.

Project results are expected to contribute to all of the following objectives of the Clean Hydrogen JU SRIA, (especially for Pillar 2, Hydrogen Storage and Distribution –Sub Pillar: HRS):

- Availability [%]: >97% in 2024 and 99% in 2030
- Mean time between failure [d];
    - For 700 bar: 72 in 2024 and 168 in 2030
    - For 350 bar: 144 in 2024 and 336 in 2030
    - For liquid hydrogen: 216 in 2024 and 504 in 2030
- HRS contribution in hydrogen price [€/kg]:
    - For 700 bar: 3 in 2024 and 2 in 2030
    - For 350 bar: 2 in 2024 and 1.25 in 2030
    - For liquid hydrogen: 3 in 2024 and 2 in 2030

Scope

It is expected that scalable bunkering solutions will best be developed through the demonstration of innovative systems which can deliver hydrogen to vessels safely, quickly and at low cost. The technical development for these solutions should be accompanied by work to understand the underlying physical phenomena, develop health and safety practices, satisfy existing and suggest new regulatory requirements as needed, deliver appropriate classification of the solutions developed, and facilitate wide roll out of the solution. Previous desk-based studies have proposed the development of a corridor of hydrogen bunkering hubs at key connecting ports across Europe, and it is expected that this initiative will be tied to a location with developed offtake for compressed hydrogen gas. To realise these ambitions, standardisation of the developed engineering solutions, including components such as refueller, connections, nozzles, as well as of fuelling protocols, is also a key priority.

There are a number of different approaches to developing appropriate bunkering solutions, which will be more or less relevant according to local requirements. Maximum impact for the action will be secured by tying the solution developed to a local need, to enhance the commercial case for the adoption of the solutions developed. To ensure that the solutions developed address the full range of challenges foreseen, the action should focus on one of two distinct focus areas:

- A pipe-to-ship stationary refuelling solution which is multi-modal, in that it can address refuelling requirements for a range of vehicles including trains and trucks, as well as account for refuelling for shore-to-ship power. The infrastructure and fuelling protocols should be designed for simultaneous bunkering operations and should be able to scale in future;
- A floating ship-to-ship or platform-to-ship bunkering system and protocol, to facilitate efficient hydrogen delivery without the need for vessels to visit a port or stationary refuelling station, as well as to provide resilience and redundancy. If this focus area is selected, then the successful project should cooperate with the successful project of HORIZON-JTI-CLEANH2-2022-03-05, working on the barge-to-barge bunkering.

Proposals should also:

- Demonstrate a smart and safe logistics solutions and develop a market standard to support front-running shipping projects;
- Evaluate the proposed solutions from technical and economic points of view, including robustly considering business models and the cost of hydrogen delivered;
- Address health, safety and environmental considerations, and should take account of standards in development internationally;
- Specifically, build upon existing blueprints deriving from liquified natural gas protocols and international standards developed for those. To this end project consortia should seek to involve key sector stakeholders, such as port authorities, classification societies, ship designers, ship owners and specifically international organisation such as the Society of International Gas Tanker and Terminal Operators (SIGTTO), the International Association of Ports and Harbours (IAPH) and the Society for Gas as a Marine Fuel (SGMF);

Ensure to build upon best practice developed in current and near-term pilot projects wherever possible.

The HORIZON-JTI-CLEANH2-2022-02-11 and HORIZON-JTI-CLEANH2-2022-03-05 topics are highly complementary and synergies between the two should be sought by applicants. As the scope of the project is embedded within the activities of other partnerships, namely the Zero Emission Waterborne Transport (ZEWT) co-programmed partnership, cooperation with them should also be pursued.

This topic is expected to contribute to EU competitiveness and industrial leadership by supporting a European value chain for hydrogen and fuel cell systems and components.

Proposals should provide a preliminary draft on ‘hydrogen safety planning and management’ at the project level, which will be further updated during project implementation.

It is expected that Guarantees of origin (GOs) will be used to prove the renewable character of the hydrogen that is used. In this respect consortium may seek out the purchase and subsequent cancellation of GOs from the relevant Member State issuing body and if that is not yet available the consortium may proceed with the purchase and cancellation of non-governmental certificates (e.g CertifHy[52]).

[52] https://www.certifhy.eu/

HYDROGEN END USES: TRANSPORT APPLICATIONS

TC3-01 Development and optimisation of reliable and versatile PEMFC stacks for high power range applications

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of around EUR 3.5 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 7.00 million.
Type of Action	Research and Innovation Action
Technology Readiness Level	Activities are expected to start at TRL 3 and achieve TRL 5 by the end of the project See General Annex B.
Procedure	The procedure is described in General Annex F. The following exceptions apply: To ensure a balanced portfolio covering complementary approaches , grants will be awarded to applications not only in order of ranking but at least also to one additional project that is / are complementary, provided that the applications attain all thresholds.

<u>*Expected outcome*</u>

Developing and deploying cost-competitive and mature Hydrogen Fuel Cell technology by 2030 is crucial for reaching EU's aim of reducing greenhouse gas emissions while maintaining economic growth. Innovative solutions addressed by the proposals submitted for this topic will contribute to the clean and sustainable transition of the transport sector towards climate neutrality, targeting here its exploitation primarily for road transport, while considering possible spill over benefits for maritime, rail and aviation. The major expected long-term impact is an actual support to cost-competitive deployment of reliable Fuel Cell based heavy duty land transport, thanks to advances in the PEMFC stack which is the core and one of the main technology building blocks for fuel cell-based propulsion systems.

Cost, power density, efficiency and durability are the key parameters for successful fuel cell stack implementation in heavy duty transport applications. The final outcomes will be enhanced performance and durability assessed at stack level, through optimised and sustained operation validated at high efficiency under high load. These results will also facilitate integration and the adaptation of the innovative solutions to various user profiles and applications, taking into account hybridisation and fair compromise between stack and system performance.

Project results are expected to contribute to all of the following outcomes:

- Deployment of the developed solutions by PEMFC stack manufacturers (2027);
- Uptake of the developed solutions by Fuel Cell system developers for their further implementation in trucks, ships, aircrafts or trains (2030);

- Contribution to Clean Hydrogen JU SRIA KPIs (2024 and 2030) on PEMFC stacks and systems for road transport applications;
- Identification of new possible routes or breakthrough for PEMFC based on new knowledge (>2030);
- Proposal of technical ideas adaptable for developments of FC systems for ships, trains or aircrafts (>2030);
- Contribution to Regulation Codes and Standards in the fields of PEMFC or hydrogen for transport (continuously).

Project results are expected to contribute to all of the following objectives of the Clean Hydrogen JU SRIA:

- Ready-for-integration solutions for high efficiency PEMFC stacks, demonstrating required cost, durability and performance;
- Innovations and advances to mitigate issues for both high power and high efficiency usage: on comprehensive operating strategy of the PEMFC; on design of the cell unit; or on design of the overall stack;
- Improved knowledge on performance limitations and degradation issues for these high power PEMFC.

Quantified indicators, included in the Clean Hydrogen JU SRIA KPIs (for 2024) for assessment of these objectives are:

- An increase in efficiency versus the stated starting point. Proposals should hence specify the starting point for the technology and system considered." A FC stack durability of 20,000 hours with beginning of life power density of 1.0 W/cm² at 0.675V. Both should be demonstrated following boundary conditions given in the scope;
- A global stack cost lower than 75 €/kW and a PGM loading of 0.35 g/kW. Given that the scope is focused on technical improvements of the stack technology, not including direct cost reduction, nor MEA components development, the purpose will be to assess the indirect impact on cost and on specific PGM-loading [g/kW] of the innovations and developments conducted;
- Agreed validated protocols representative of targeted usage as needed for appropriate assessment of KPIs. Different types of use can be considered including the power demand of balance of plant and auxiliary devices;
- Supplementary outcomes can be promoted such as: new methodologies or tools, new measurement or simulation methods, characterisation or testing protocols, numerical simulation software or services;

Scope

Advances in the PEMFC stacks technology are needed to support deployment of Fuel Cell heavy duty transports. Cost-competitive and reliable integration require stack solutions particularly tailored for sustained operation at high stack-power. Proposals should focus on applicability of their developments in the field of land transport, primarily road, while considering possible spill over benefits for maritime, rail and aviation

Proposals should address innovative concepts, designs, methods and/or operating-strategies. Related investigations may tackle cell and stack levels, including flow-fields, bipolar plates or assembling features (e.g. mechanical aspect), as well as the range, the distribution or the management of the operational conditions (e.g. thermal or reactant gases feeding aspects). The overall process should build on comprehension of the currently proven PEMFC technology and further development at stack level targeting optimised operation for high efficiency and extended durability at high stack power density. For the range of power envisioned, increasing efficiency would enhance the overall system with respect to volume savings for fuel storage.

Innovation on MEA is out of scope of this topic. Work should therefore be conducted on validated components, including commercialised or developed in other actions. Availability of baseline features on MEA should be a prerequisite: for commercial or promising R&D products, agreement of companies or developers to provide needed parameters and to allow deep analysis as relevant for reaching expected outcomes is needed. Maximum total loading should be 0.5 mg PGM/cm².

Optimisation should be supported by advanced experimental and simulation tools to analyse the impact of stacks features on their functional properties (e.g., performance level and limitations, voltage losses, electrochemical characteristics) regarding application requirements and system specifications. Local insights, especially meaningful for the large active area considered, should be assessed for different zones, between cells and across interfaces by in- and ex-situ characterisations and by simulations using cell- and stack-design based models. A better specific understanding of global and local mechanisms, occurring in cells and stacks operated at high power and affecting both performance and degradation, should be acquired thanks to spatially distributed analyses. Data will be used to clarify the influence of components, design, assembly or working features (e.g., load profiles, conditions and events). Developed experimental, monitoring or model-based approaches should be exploited to promote expected innovations and advances on comprehensive operating strategy of the PEMFC and on design of the cell unit or of the overall stack.

Compliance with the targeted KPIs, assessment of progress and final validation should be examined at stack scale (minimum 5 kW, or 10-cell-stack and scale-1 cell surface) under relevant conditions representative of actual use, taking into account system requirements for the targeted applications. Validated agreed protocols (including accelerated testing) should be applied to confirm and quantify improvements in areal power density, stack or system efficiency and lifetime. These protocols will be developed within the project if needed or selected in agreement with previous initiatives and in cooperation with relevant applicative roadmaps.

Focusing the development on advanced research work while monitoring progress and validating final optimisation at representative scale under protocols and conditions relevant for system level, is expected to achieve expected outcomes with efficient innovative solutions applicable for short-term integration.

Proposals should, where relevant, build on previous/on-going FHC JU projects[53] addressing transport and similar activities, aligning particularly with: ID-FAST, IMMORTAL or MORELife regarding degradation understanding or ageing protocols; INSPIRE, DOLPHIN for developments on stacks; STaSHH for outcomes related to stack integration.

Proposals should demonstrate how the results would benefit to the whole industry, while protecting intellectual property for the involved partners. With this in mind, proposals should include public deliverables and describe how project data will be made available to the large

[53] https://www.clean-hydrogen.europa.eu/projects-repository_en

public.

Consortia should include at least one partner in the consortium for the exploitation of the project results and willingness to exploit the results should be demonstrated. It is encouraged to include actors from research and industry, the latter being interested in PEMFC stacks or system deployment.

Activities developing test protocols and procedures for the performance and durability assessment of electrolysers and fuel cell components proposals should foresee a collaboration mechanism with JRC (see section 2.2.4.3 "Collaboration with JRC"), in order to support EU-wide harmonisation. Test activities should adopt the already published EU harmonized testing protocols[54] to benchmark performance and quantify progress at programme level.

[54] https://www.clean-hydrogen.europa.eu/knowledge-management/collaboration-jrc-0_en

TC3-02: Innovative and optimised MEA components towards next generation of improved PEMFC stacks for heavy duty vehicles

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of around EUR 3.00 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 6.00 million
Type of Action	Research and Innovation Action
Technology Readiness Level	Activities are expected to start at TRL 2 and achieve TRL 4 by the end of the project See General Annex B.
Procedure	The procedure is described in General Annex F. The following exceptions apply: To ensure a balanced portfolio covering complementary approaches , grants will be awarded to applications not only in order of ranking but at least also to one additional project that is / are complementary, provided that the applications attain all thresholds.

<u>*Expected outcome*</u>

Hydrogen as fuel in transportation has significant advantages compared to pure battery electric propulsion, especially for heavy duty applications. But these applications require higher power and much longer lifetimes than those developed and achieved for SoA passenger cars. Further improvements of SoA components of MEAs represent a major opportunity for both increasing the areal power density and long-term durability of PEMFCs. Innovations should address the core components of MEAs – membrane, catalyst layer, microporous layer and gas diffusion media – and specifically their interactions within an MEA.

Project results are expected to contribute to all of the following expected outcomes:

- Contribute to paving the road for increased competitiveness of and market shares for European fuel cell companies in the emerging global market for PEMFC technologies in transport;
- Improvement of overall system performance of FC systems in order to improve the availability and durability and meet the needs of FCH heavy duty vehicle (HDV) end-users;
- Improvements in design and monitoring procedures of FC systems;
- Provide MEA components that contribute to the achievement of the SRIA KPIs for HDV;
- Improve the understanding and prediction of MEA performance and lifetime;
- Support the development of specific applications for MEAs (particularly for HDV, but

also transferable to rail, aviation, maritime etc) by means of materials characterisation and parameterisation of material properties;

- Provide models that support European companies developing new MEA and MEA materials and components. Enable these target groups to simulate the influence of MEA material properties on performance and degradation processes. Such physics-based MEA models are expected to become part of their workflow which is necessary to develop competitive application-specific MEAs with high durability;
- Up-take of MEA parameterisation, simulation, and support services by the target groups to strengthen the European value chain on fuel cell stacks;
- Increasing fuel efficiency during the whole FC lifetime and thereby foster the market introduction of HDV;
- Contribute to harmonisation of testing protocols for quantification of MEA performance and lifetime, including accelerated stress tests.

This topic addresses objectives for hydrogen end uses in transport applications, sub-pillars Building Blocks and HDV. In particular, project results are expected to contribute to all of the following objectives of the Clean Hydrogen JU SRIA:

- Improvement of the overall system performance for fuel cell stack technology in terms of power density, reliability and durability (KPIs for low TRL in 2024: Power density of 1.2 W/cm2@0.65 V, FC stack durability of 20,000 h);
- Reduction of PGM loading (KPI: PGM loading for low TRL < 0.30 g/kW in 2024);
- Contribute to the reduction of the FC stack cost for HDV (KPI: < 75 EUR/kW in 2024) through affordable MEA materials and components and cost of manufacturing;
- Improvements in the design and health monitoring of core components for FC stacks;
- Improvement of overall system performance of FC systems in order to improve the availability and durability and meet the needs of FCH HDV end-users;
- Improvements in design and monitoring procedures of FC systems.

Scope

Despite substantial research work continuously conducted in the field, the knowledge acquired so far shows that SoA components or methods followed for their enhancement do not reach the performance and lifetime targets for heavy duty transport. This topic is focused on building blocks for HDV with an expectation for synergies, adaptability, and compatibility with other areas such as maritime, aviation, trains etc. Challenges to be addressed by proposals are:

- Durable and active catalysts and advanced supports are required to achieve high ORR activity and to assure long lifetime by mitigation of ECSA loss, and reduction of oxygen transport resistance. The end of life (EoL) performance of MEA in HDV applications needs to be simulated and experimentally assessed.
- The chemical and mechanical stability of the PEM can limit the lifetime in HDV applications especially at increased operating temperatures. Therefore, robust and durable membranes and ionomers are essential.
- Electrode design needs to be improved to meet the HD KPIs involving tailored ionomer loading, Pt particle size distribution and location, as well as improved

catalyst ionomer interaction. The challenge is to tailor electrodes for HDV applications, where electrocatalyst-ionomer interactions and integration is improved and PGM loading is reduced.

The approach should be based on an analysis of the limitations of MEA components in terms of particularly lifetime and fuel efficiency and held against the targets for the next generation technology.

A combination of materials characterisation, optimised catalysts – support interaction, MEA fabrication, testing and modelling is considered the key to gain deeper understanding of the limitations involved in previous generation stack components. Quantification of barriers to the fluxes of mass, energy, charge, and momentum at target operating conditions of MEA for HDV is needed to progress on tailored materials and controlled structures.

Innovative materials (catalyst, catalyst support, ionomer, hydrophobic/hydrophilic treatments etc.) and components (membrane, catalyst layer, microporous layer and gas diffusion media) are expected to be fabricated and characterised at lab scale. Possible developments are, for example, membranes that are stable at high temperature (up to 120°C), high activity catalysts that are stable, improvement of the catalyst support to avoid corrosion of carbon at high voltage (start/stop) etc.

The structure of components and interfaces should be improved reflecting operational conditions representative for heavy duty application. Analysis, optimisation, and lifetime prediction of MEA should be supported by SoA multiscale simulation. MEA models should capture the coupled transport of heat, charge, and mass, and electrochemical reactions in all MEA components and across all interfaces, including two-phase water transport, heat production/cooling. It is important to account for antagonistic transport effects to determine the impact of changes in materials, components, interfaces properties, morphology or dimension on the performance of cells and on degradation processes. Validation strategies should be based on accelerated stress tests representative for heavy duty applications and component-specific simulation of different degradation processes.

Reproducible MEA structures and properties are prerequisites to assess MEA performance limitations and to identify transport barriers. Existing fabrication processes applied to integrate new materials/components within innovative MEA or specifically developed to realise new materials/components or structures should be demonstrated. Innovation on MEA components is also expected from the design, fabrication and analysis of alternative MEA constructions, including the reduction of PGM content, recovery of waste and recycling of components, thus facilitating the adoption of the circular economy principles. Variation of morphology, hydrophobicity, Pt content, and adaption of MEA structures to the flow-field etc. are possible approaches.

Innovation can be reached by improved model parameterisation from ex-situ characterisation of materials/components/interfaces properties, morphology. For instance, there is a significant uncertainty in the properties of commercially available components, especially of catalyst layers, microporous layers or membranes made of composite materials. The ionomer transport properties, either in the catalyst layer or in the membrane (hydration, electroosmotic drag, water diffusivity, protonic conductivity), need to be better parameterised.

Improving MEA durability in relevant testing environment without sacrificing performance is a key aspect of this topic. Therefore, MEA degradation modelling is expected to address the different sub-components of the MEA (e.g. catalyst, GDL, MPL, catalyst layer, ionomer) and their interactions. MEA simulation may also be used to predict the relation between operating temperature, cell voltage and the durability of electrodes and membranes.

Test hardware capable for reliable model parametrisation should be developed or be available for the implementation and the test of both performance and durability of reference and developed MEA. Project consortia should include the capability to manufacture MEA compatible with high volume manufacturing to ensure future exploitation potential to be reached. Final validation of MEAs should be performed by using single cells and possibly in short stacks in-line with EU standardisation activities. MEA durability assessment should be performed on the cell level for a minimum of 1,000 hours of operation with extrapolation possibly up to 20,000 hours. Access to OEM single cell/stack testing hardware for final validation is requested.

Target groups are companies fabricating MEA components, MEAs, and the scientific community working on new materials and components.

A TRL 4 should be targeted as final TRL considering the current state of the art MEA used in LDV applications and related knowledge and experience from the previous FCH JU projects [55](e.g. GAIA, Immortal). Development of PGM free catalysts, new fabrication and scale up processes are out of scope. Work will be conducted on SoA fabrication methods of Pt or Pt alloys/C based catalyst layers and should consider the recovery and recycling of by-products and waste. A company being able to manufacture MEAs should be part of the consortium for better exploitation value. Participation of an OEM or a stack manufacturer is encouraged. At least, an OEM should be part of the project's advisory board. Projects should build synergies with current projects[56] on MEA/components development for light-duty applications (e.g. FURTHER-FC, DOLPHIN, GAIA). Agreement of companies to extract material parameterisations by ex-situ characterisation should be sought to gain predictive numerical simulation results.

Proposals are expected to address sustainability and circularity aspects.

Activities developing test protocols and procedures for the performance and durability assessment of electrolysers and fuel cell components proposals should foresee a collaboration mechanism with JRC (see section 2.2.4.3 "Collaboration with JRC"), in order to support EU-wide harmonisation. Test activities should adopt the already published EU harmonized testing protocols[57] to benchmark performance and quantify progress at programme level.

[55] https://www.clean-hydrogen.europa.eu/projects-repository_en
[56] https://www.clean-hydrogen.europa.eu/projects-repository_en
[57] https://www.clean-hydrogen.europa.eu/knowledge-management/collaboration-jrc-0_en

TC3-05: Large scale demonstration of European H2 Heavy Duty Vehicle along the TEN-T corridors

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of around EUR 30.00 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 30.00 million
Type of Action	Innovation Action
Technology Readiness Level	Activities are expected to start at TRL 7 and achieve TRL 8 by the end of the project See General Annex B.
Admissibility conditions	The conditions are described in General Annex A. The following exceptions apply: The page limit of the application is 70 pages.
Eligibility	The conditions are described in General Annex B. The following additional eligibility criteria apply: At least one partner in the consortium must be a member of either Hydrogen Europe or Hydrogen Europe Research. The maximum Clean Hydrogen JU contribution that may be requested is EUR 30.00 million – proposals requesting Clean Hydrogen JU contributions above this amount will not be evaluated.
Legal and financial set-up of the Grant Agreements	The rules are described in General Annex G. The following exceptions apply: Purchases of equipment, infrastructure or other assets used for the action must be declared as depreciation costs. However, for the following equipment, infrastructure or other assets purchased specifically for the action (or developed as part of the action tasks): trucks, fuel cell system, on-board hydrogen storage and other components needed in a hydrogen truck, costs may exceptionally be declared as full capitalised costs.

Expected outcome

Hydrogen has proven to be the alternative to conventional ICE operated on fossil fuels, especially for long range and flexible zero emission (ZE) Heavy Duty (HD) mobility, where direct electrification with large batteries cannot meet the intensive usage and payload requirements. Large scale fleet deployments and operations are needed. Wheels on the roads, operated by different operators in different EU markets and geography, providing insight on relevant business cases for potential buyers, and then the respective refuelling infrastructure in order to guarantee the long-haul distance are needed.

Hydrogen mobility currently is not always perceived as a viable zero emission alternative against ICE and BEV. Allowing relevant fleet owners and operators to experience first-hand the technology would play an important role in changing this perception of the technology. Furthermore, their lighthouse function will set an example for many other potential end-users, who can benefit from the experience of the ‘front-runners’. Next to this, the parallel introduction of multiple fleets throughout a variety of operations, in multiple EU Member States, will increase the credibility of hydrogen as a commercial alternative. For this to happen it is necessary to break through the current vicious circle (small quantities because of high prices and high prices because of small quantities).

This flagship[58] topic aims to address all of the aspects above mentioned via the deployment of a large fleet of fuel cell HDV across several countries and use cases.

Current research shows that boosting economies of scale on the short term, will enable hydrogen to become economically feasible as from 2025. In this sense this project represents a critical step in that direction. It will initiate and substantially accelerate the initial cost reduction of fuel cells trucks by enabling the relevant supply chains to reach critical mass, which in turn will accelerate the attainment of the Total Costs of Ownership (TCO) competitiveness.

As enabler, heavy-duty, long-haul truck has proven to be the ideal market-segment for doing this. It is often forgotten that the market size, combined with the total energy consumption, and a high potential to generate (concentrated) vehicle fleets, provides the ideal situation to function as a flywheel for other markets. Current market research is expecting 100,000 vehicles in 2030 and growing to >100,000 hydrogen trucks per year (representing 25-30% of the yearly truck sales). The end goal is to make hydrogen for Heavy Duty applications economical viable without funding’s in the next 5-10 years.

Studies show that biofuels and BEVs alone will not be sufficient to meet the targets set out by the CO_2 standards for heavy duty vehicles regulation, which mandates OEM to reduce by 30% the average CO_2 emissions of the highest emitting HDV segments by 2030, or the broader EU goals of carbon neutrality by 2050. Therefore, there is a growing consensus that a market for hydrogen long haul Heavy Duty Trucks will be the key enabler to generate the critical mass, in volume, for hydrogen components. This can boost the market potential of hydrogen technology and, as a result, reduce the component price to get competitive TCO through economies of scale. This will lead to more knowledge and data of hydrogen as an alternative fuel and will increase improved levels of service: both on parts availability and on trained service people, also concerning the refuelling activities, throughout Europe. Additionally, a broad range of fields where hydrogen applications are being developed (e.g. rail, maritime, off-road but also stationery applications) will benefit from the development of hydrogen trucks through spill-overs, subsequently developing EU supply chains.

In earlier programs the feasibility of hydrogen in distribution trucks was demonstrated (H2Share[59] 27 tonne and Hydrogen Region 2.0[60] 44 tonne truck). The FCH JU funded H2Haul[61] project intends to upscale the tractor truck to long haul operation along defined corridors near the operator.

In total 16 trucks will be deployed in the H2Haul project. As seen in comparable markets, such as public transport, a logical transition step for operators is to start with a demonstrator, then move to a small series and towards a first fleet of 20 to 40 vehicles, before they have

[58] For definition of flagship see section 5.3. of the Clean Hydrogen JU Strategic Research and Innovation Agenda 2021 – 2027

[59] https://www.nweurope.eu/projects/project-search/h2share-hydrogen-solutions-for-heavy-duty-transport/

[60] https://www.waterstofnet.eu/en/hydrogen-region-2-0

[61] https://www.clean-hydrogen.europa.eu/projects-repository_en

fully embraced the technology as a 'normal' alternative. These single fleets will drive the OEM and suppliers forward as they need to work in parallel to be able to provide the right product and service proposition. To this end, the FCH JU funded StasHH[62] project aims to define a standardised fuel cell module in order to facilitate growth and economy of scale.

Therefore, the next step (before hydrogen trucks can be delivered at large scale in the Important Projects of Common European Interest (IPCEI projects) are the flagships projects: allowing the truck agglomerates (OEM) to have a hydrogen truck ready for sale in limited numbers and to integrate the hydrogen truck as platform in their product line and service organisation. Furthermore, the data collected in such a flagship project is key to allow truck manufacturers and transport companies to strengthen and validate the operational and financial viability of hydrogen trucks for daily operation.

A critical success factor is the network of HRS to ensure the hydrogen refill demand is available on the route showing the hydrogen trucks long haul capabilities along major transport corridors throughout Europe. In addition, a truck refuelling market could enable a faster deployment of HRS and a lower price of hydrogen delivered thanks to higher volume associated than when solely supplying light duty vehicles.

Project results are expected to contribute to all of the following expected outcomes:

- Economy of Scale for all hydrogen components, and as a result demonstrate a significant decrease in TCO per tonne per km by truck OEM, HRS operators and transport companies working together, making heavy duty hydrogen trucks operationally and financially viable;
- Increase in sales of the total volume of trucks as similar TCO decreases can be expected in other markets and applications (e.g.: refrigerating trucks);
- Contribute to the expansion of the hydrogen truck service network and HRS network through Europe and along the TEN-T core and comprehensive network. This should require OEM agreement to mitigate the risk of creating stranded assets and to concentrate resources;
- The creation of a competitive offering of several models of hydrogen trucks (from different truck OEM) and creating added value for the European Industry;
- Promote hydrogen trucks and refuelling as an operationally and financially viable alternative for BEV trucks and biofuels, contributing to the resolution of a maximum scope of technological (e.g. lifetime and durability, HRS/truck compatibility), operational (e.g. driving range, payload capacity, refuelling time), regulatory (e.g. tax exemptions and incentives), and financial challenges (TCO), making hydrogen trucks operationally and financially viable for transport companies in Europe;
- Comparison of the different zero emission trucks on performance, range, environment, TCO, etc;
- Gathering of relevant technical and financial data in different conditions from truck operation: like range, speed-, load profile, refuelling time and the supply of hydrogen: (public) pipeline network, tube trailer (different pressures), local electrolysis etc;
- Providing a growing market that becomes increasingly interesting for competition between hydrogen component suppliers and enabling the transition from job shop and batch manufacturing towards mass production of hydrogen trucks and HRS;

[62] https://www.clean-hydrogen.europa.eu/projects-repository_en

- Demonstrate the implementation/feasibility of harmonised legislation extended to HD trucks (UN R134) by the main truck OEM in Europe;
- Strong dissemination and awareness program, involving a maximum number of transport companies;
- Fostering innovative truck operator business models lowering the financial, operational and technological risk barrier for transport companies to adopt hydrogen trucks. Strengthening global competitiveness of European truck OEM in the heavy-duty truck segments;
- As international operation is foreseen, a broad spectrum of use cases is covered (climate, road conditions, daily operations);
- Limit the cost per truck below EUR 450,000. In addition, it is also expected to see the cost of trucks decrease throughout the duration of the action. OEM in the project should monitor and report on the cost evolution.

Hydrogen will be one of the dominant solutions enabling Horizon Europe to contribute to a more liveable and Carbon neutral Europe towards 2050. The 'Hydrogen Economy' (Users and Suppliers) will benefit from the approach of this proposal. This flagship project on hydrogen trucks will contribute to this by the fact that developments will shift from technology into applications (EU wide) and thus will accelerate the use of hydrogen as an alternative fuel. This will result in the critical reduction of costs in order for Hydrogen to settle as an operationally and financially viable alternative to ICE and BEV. The end goal is to make hydrogen for Heavy Duty applications economical viable without funding's in the next 5-10 years.

Project results are expected to contribute to all of the following objectives of the Clean Hydrogen JU SRIA:

- Availability of trucks: 90%;
- Average consumption of trucks: proposals should specify their targets, and it is encouraged to go for under 10 kg/100km for the 38-40 tonnes range;
- Kilometres driven during the project:
    - Long haul: 60,000 km/year/truck;
    - Distribution: 40,000 km/year/truck;
- Each truck should be operated for a minimum of 2 years;
- Range for 50% of the trucks > 600km

and proposal for a regulation on the deployment of alternative fuels infrastructure 2021/0223(COD)[63]

Hydrogen Refuelling Infrastructure (HRS)

It is expected that the refuelling infrastructure accompanying the fleet of trucks to deployed in the project should be in line with the guidelines of the proposal for a regulation on the

[63] https://ec.europa.eu/info/sites/default/files/revision_of_the_directive_on_deployment_of_the_alternative_fuels_infrastructure_with_annex_0.pdf

deployment of alternative fuels infrastructure 2021/0223(COD)[64], in particular:

- One HRS every 150 km (or every 450 km in case of LH_2) on both core and comprehensive TEN-T network and in each urban node[65]
- Ability to refuel at 350 & 700 bar, minimum capacity of 2 t/day

In addition:

- HRS availability: 95%;
- Refuelling operation: 6 kg/min @700 bar
- The inclusion of HRS allowing refuelling under 10 minutes for Liquid Hydrogen (LH_2); is encouraged;

Scope

To produce and operate a minimum of at least 150 homologated fuel cells hydrogen trucks, including a service/maintenance/dealer/parts network along defined comprehensive TEN-T[66] corridors throughout Europe and to operate them supported by a backbone of HRS for a minimum of 2 years, the following actions should be addressed in the proposals:

- Minimum 150 hydrogen trucks delivered by at least 3 different truck OEM (not part of the same group), with a minimum of 20 trucks per OEM cluster. The cost per truck should remain under EUR 450,000€, unless properly justified and a short term path to achieve the cost goal will be presented;
- Minimum 6 operators from as many different EU countries along the core and comprehensive TEN-T corridor(s). It is suggested to have as many transporters/shippers as possible in order to trigger a significant impact on dissemination activities. Links among a number of the deployment sites are strongly encouraged (i.e. proximity leading to sharing of HRS);
- The trucks can be tractor or rigid based with a minimum tonnage of 19 tonnes for rigid and a minimum tonnage of 37 tonnes for tractors. More than 65% of the trucks should be long haul and > 37 tonnes. Vans are excluded from funding;
- The fuel cell vehicles powered with hydrogen should be capable of long-haul operation and they should be deployed along the core and comprehensive TEN-T corridors;
- The minimum range of 50% of the trucks should be 600 km without refuelling under all driving conditions. The rest of the trucks can target a regional intensive use with, if needed, two (local) refilling's per day and a minimum range of 400 km without refilling;
- The vehicles should operate for a minimum of 40,000 km or 60,000 km (according to the truck type) per year, per truck, per operator for a minimum of 2 years. The operational data of these trucks has to be gathered and processed by an

[64] https://ec.europa.eu/info/sites/default/files/revision_of_the_directive_on_deployment_of_the_alternative_fuels_infrastructure_with_annex_0.pdf

[65] Following AFIR guidance, Article 6. https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A52021PC0559

[66] https://transport.ec.europa.eu/transport-themes/infrastructure-and-investment/trans-european-transport-network-ten-t_en

independent organisation. Such organisation could be a partner, but independent from trucks' suppliers;

- Include a data monitoring strategy (with minimum parameters to be monitored) that would allow evaluate the overall financial, environmental and technical performance of each of the truck operation profile / fleet in the project in sufficient detail. In addition, a sufficient subset of the trucks (representative of each OEM fleet and of the use cases) should be placed under a detailed data monitoring to gather relevant information at truck level (speed, load profile, journeys, etc). Costs related to the monitoring equipment are eligible;
- The truck models deployed in the framework of the project should become commercially available in limited numbers after the project in order to increase real-time data gathering and improve the next generation Heavy-Duty hydrogen vehicles;
- In order to stimulate the EU hydrogen and fuel cell market, for each vehicle the share of main hydrogen subsystems –originated from the EU should be reported;
- The truck OEM, HRS operators and transport companies such as transporters and shippers (their adhesion are key to ensure the success of the initiative), should cooperate to contribute to the adoption of regulatory incentives and technical harmonisation of hydrogen trucks and HRS on a European level;
- Innovative business models are encouraged such as turn-key solutions to end-users and/or leasing;
- An overall plan for deployment (with different stages) that goes beyond the timeline of this project should be foreseen. The needs of support for later stages should be justified in view of closing the funding gap in a dynamic environment where hydrogen trucks become increasingly competitive with incumbent technologies.

Proposals should contain a calendar clearly defining the key phases of the implementation of the action (i.e. preparation of the specifications of trucks and HRS, manufacturing, deployment and operation) and their duration. Proposals should foresee enough time for monitoring and assessment. In that respect proposals are therefore encouraged to put forward ambitious deployment plans including the deployment of a significant percentage of the fleet withing the first 2 years of the action, in order to fully unlock the potential of European FCH solutions in the HD segment and contribute to the EU CO_2 emission standards for new heavy-duty vehicles (EU 2019/1242) targets.

The refuelling infrastructure and its associated costs are not in the scope of this topic. Applicants are therefore strongly encouraged to seek support from alternative sources of funding and/or financing and provide such additional plan to minimise the risk of the implementation of vehicles and associated infrastructure and maximise its impact.

Applicants are therefore encouraged to submit complementary proposals to Clean Hydrogen JU (for the deployment of the vehicles) and to CEF Transport (for the deployment of the refuelling infrastructure)[67].

Furthermore applicants may consider additional synergies with other Programmes (e.g.

[67] The Connecting Europe Facility (CEF) for Transport (CEF-T) work programme 2021-2023 has a 3-year rolling call running for the Alternative Fuel Infrastructure Facility, with deadlines every 6 months, https://ec.europa.eu/inea/en/connecting-europe-facility/cef-transport#:~:text=The%20Connecting%20Europe%20Facility%20(CEF,and%20upgrading%20the%20existing%20one.

European Structural and Investment Funds, Recovery and Resilience Facility, Just Transition Fund, Connecting Europe Facility, Innovation Fund, Modernisation Fund, LIFE, etc) and/or clustering with other projects within Horizon Europe or funded under other EU, national or regional programmes, or having loans through the EIB or other promotional or commercial banks; such synergies should be reflected in a financing structure and strategy describing the business model, including envisaged sources of co-funding/co-financing and in line with state-aid rules.

Additionally synergies with the 2ZERO partnership topic HORIZON-CL5-2022-D5-01-08[68] should be explored and developed where possible.

This topic is expected to contribute to EU competitiveness and industrial leadership by supporting a European value chain for hydrogen and fuel cell systems and components.

It is expected that Guarantees of origin (GOs) will be used to prove the renewable character of the hydrogen that is used. In this respect consortium may seek out the purchase and subsequent cancellation of GOs from the relevant Member State issuing body and if that is not yet available the consortium may proceed with the purchase and cancellation of non-governmental certificates (e.g CertifHy[69]).

Proposals should provide a preliminary draft on 'hydrogen safety planning and management' at the project level, which will be further updated during project implementation.

Activities developing test protocols and procedures for the performance and durability assessment of electrolysers and fuel cell components proposals should foresee a collaboration mechanism with JRC (see section 2.2.4.3 "Collaboration with JRC"), in order to support EU-wide harmonisation. Test activities should adopt the already published EU harmonized testing protocols to benchmark performance and quantify progress at programme level.

[68] https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/horizon-cl5-2022-d5-01-08
[69] https://www.certifhy.eu/

TC3-06: Liquid hydrogen tanks for heavy-duty vehicles

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of around EUR 2.5 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 5.00 million.
Type of Action	Research and Innovation Action
Technology Readiness Level	Activities are expected to start at TRL 4 and achieve TRL 6 by the end of the project. See General Annex B.
Procedure	The procedure is described in General Annex F. The following exceptions apply: To ensure a balanced portfolio covering complementary approaches , grants will be awarded to applications not only in order of ranking but at least also to one additional project that is / are complementary, provided that the applications attain all thresholds.
Legal and financial set-up of the Grant Agreements	The rules are described in General Annex G. The following exceptions apply: Beneficiaries must, up to 4 years after the end of the action, inform the granting authority if the results could reasonably be expected to contribute to European or international standards.

<u>*Expected outcome*</u>

Commercial trucks are responsible for a quarter of road transport CO_2 emissions. For the decarbonisation of lighter and heavier commercial trucks in local transport batteries and pressure storage technologies for hydrogen are suitable. On the other hand, these energy storage systems are less suitable for heavy and long-distance transport due to their low volumetric energy density and the limited space constraints according to regulations in Europe.

Onboard LH_2 tanks could be an enabler for zero emission mobility in heavy and long-distance road transport. In comparison to the state-of-the-art 350 bar or 700 bar storage, LH_2 can enable much higher volumetric energy system density (up to double as compared to 700 bar) and simpler refuelling station design; advantages that are of utmost importance for the space, mass, time, and fuel cost constraint application. However, the actual performances of onboard LH_2 tanks are not known precisely since not enough prototype development nor testing has been performed. Critical issues such as boil-off sensitivity, achievable capacity (for a given volume) and refuelling interface need to be addressed.

This topic will provide sufficient information on the critical issues related to onboard LH_2 tanks for heavy-duty vehicles road application, so that a well-informed decision can be made by stakeholders on key technical bottlenecks to be solved or possible showstoppers for the technology.

Project results are expected to contribute to all of the following expected outcomes:

- Onboard truck demonstration of a high-density hydrogen system by 2025;
- Deployment of cost-effective, long range zero emission solutions for trucks by 2030;
- Drastically improved understanding of onboard cryogenic hydrogen storage systems challenges;
- European leadership in onboard cryogenic hydrogen storage.

By reducing the storage cost and enabling long-range truck transportation, this project will greatly contribute to the transport end-uses objectives as detailed in the SRIA of the Clean Hydrogen JU.

Project results are expected to contribute to all of the following objectives of the Clean Hydrogen JU SRIA:

- Onboard tank
    - Storage tank CAPEX: 320 Euros/kgH_2
    - Gravimetric Capacity: 10 wt%_H_2
    - Volumetric capacity: 40 gH_2/L system
    - Dormancy[70]: 48 hours
    - Venting rate[71]: <2%/day
- Refuelling solution
    - Filling rate: 8 kg/min
    - Coupling mass: < 3 kg
    - Installation time (before flowing LH_2): 30 s
    - Removal time: 30 s
    - Energy consumption:<0.5 kWh/kgH_2
    - Station boil-off: < 2%/day

Scope

The scope of the topic is the full-scale analysis of existing concepts to store LH_2 to develop and integrate an improved LH_2 vessel in at least 2 road long distance heavy duty vehicles, with over 800km range without refuelling, to evaluate the feasibility of the technology. Capacities and refuelling speeds should be in the 40-100 kg LH_2 in one or more vehicle storages depending on the vehicle design and 7-10 kg/min range, respectively. Cost estimates for the storage system should be provided.

The analysis shall contain materials, piping and instrumentation, controls, safety designs but also refuelling procedures, interfaces, and balances of plant equipment to propose modification or creation of relevant norms. Key parameters for heavy-duty road vehicles shall be the focus of the project, including easy handling and connection at the refuelling without specialised personal, effect of dormancy and boil-off, space limitation, limited volume compared to larger storages, long lasting safety equipment.

[70] dormancy/thermal autonomy is defined here as the time the vehicle should be parked without releasing any H2, irrespective of its tank's capacity or pressure, and demonstrated using real life duty cycle simulations with test bench measured insulation performance

[71] venting rate is defined as the rate of H2 that is released when the system is parked at its venting pressure

The analysis shall be done to provide improvements and optimisation on different aspects, physical parameters of the LH_2 to density, tanks composition and peripherics regarding volumetric efficiency and potential losses of hydrogen in the overall efficiency.

Proposals should focus on defining, building and understanding of a full scale LH_2 tank system for heavy duty road application and its refuelling, with at least a complete test bench fulfilling the technical readiness level. This can be completed by a refuelling solution with dispenser and/or an onboard vehicle demonstration.

Proposals should include an investigation from the end-user perspective, by simulating real-life utilisation (hydrogen extraction, driving, parking, refuelling) and making sure that the state-of-charge, the actual boil-off, and the refuelling are compatible with the expectations. Pressure in the LH_2 storage tank should be compatible with the pressure at which the fuel cell typically operates, and obviously with the boil-off target. Alternatively, mitigation strategies should be proposed. The mechanical design should be compatible with all requirements typical of the trucking industry in terms of durability, exposure to harsh environments, vibrations, accelerations, safeties, and exceptional loads e.g. fire. The validation of concepts shall occur through an experimental program backed up by simulation activities, that will allow to expend the concept to wider range of constraints.

All the activities and results should consider the current European Commission Implementing Regulation EU 2021/535[72] (liquid hydrogen storage systems) and other relevant standards. The results of the project should be used to support the development of new or revised legal requirements or standards, especially extending the scope addressed by GTR13 and its type approval part the R134. The consortium should establish links with ongoing projects[73] dedicated to relevant applications such as H2HAUL and PRHYDE/project funded under Call 2018 “Topic FCH-04-2-2019: Refuelling Protocols for Medium and Heavy-Duty Vehicles”. The consortium should take into account current activities concerning LH_2 storage, such as the subcooled LH_2 fuelling method developed within an open working group at the Clean Energy Partnership[74].

The following activities are considered to be out of scope for this topic: liquefaction technologies, well-to-wheels costs, liquid hydrogen supply chain.

[72] https://eur-lex.europa.eu/eli/reg_impl/2021/535/oj
[73] https://www.clean-hydrogen.europa.eu/projects-repository_en
[74] https://cleanenergypartnership.de/en/home-engl

TC3-09: Large scale demonstration of hydrogen fuel cell propelled inland waterway vessels

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of around EUR 15.00 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 15.00 million
Type of Action	Innovation Action
Technology Readiness Level	Activities are expected to start at TRL 6 and achieve TRL 8 by the end of the project See General Annex B.
Admissibility conditions	The conditions are described in General Annex A. The following exceptions apply: The page limit of the application is 70 pages.
Eligibility	The conditions are described in General Annex B. The following additional eligibility criteria apply: At least one partner in the consortium must be a member of either Hydrogen Europe or Hydrogen Europe Research. The maximum Clean Hydrogen JU contribution that may be requested is EUR 15.00 million – proposals requesting Clean Hydrogen JU contributions above this amount will not be evaluated.
Legal and financial set-up of the Grant Agreements	The rules are described in General Annex G. The following exceptions apply: Purchases of equipment, infrastructure or other assets used for the action must be declared as depreciation costs. However, for the following equipment, infrastructure or other assets purchased specifically for the action (or developed as part of the action tasks): vessels, fuel cell system, on-board hydrogen storage and other components needed in a hydrogen fuel cell hydrogen vessel, costs may exceptionally be declared as full capitalised costs.

<u>*Expected outcome*</u>

The total volume of goods transported via inland waterways through the 27 European Union countries was 523 million tonnes in 2019 (source: EUROSTAT); this was transported by about 12,700 cargo vessels and 2,300 tugs and push boats using cost-effective and safe logistics solutions via TEN-T transport corridors. The new targets of the Green Deal and the Fit for 55 package open new perspectives for accelerated development of inland water transportation using renewable hydrogen. Eliminating emissions from these vessels, while creating a strong commercial proposition, will boost the European waterborne transport sector and have a major positive impact on air pollution and GHG emissions. Given that inland vessels last for over 40 years, and the current (low) rate of new building, both new building and retrofitting the existing fleet are key to reaching the emission reduction targets and establishing a rapid market uptake.

The spectrum of hydrogen alternatives, the boundary conditions for successful integration as well as codes and standards are new and not widely available yet. Obligatory periodic inspection and maintenance, upgrades or retrofits are executed by many European yards. Their main expertise and experience, however, is with traditional fossil fuel and ICE technologies. The same holds for crew, bunkering and refuelling personnel, and ship owners. All should be upskilled to either design, integrate or work with hydrogen systems.

Several projects have demonstrated the feasibility of zero-emissions hydrogen propelled inland shipping. However, large scale uptake asks for a holistic approach covering the whole value chain. This includes the need for investing in public development, standardisation and integration of hydrogen propulsion and bunkering systems, a clear regulatory framework for technical execution, on-board integration, crew and bunkering personnel education and qualification, as well as a robust regulatory framework for the introduction of hydrogen as a fuel in EU waters. This will increase the uptake of hydrogen fuel cell technology and zero emission inland navigation and bring the application within reach of the sector and end-users. Ultimately, the sector should be supplied by a well distributed, resilient and consolidated market on components for retrofitting, new building and spare parts, with a fuel infrastructure that is integrated in the multimodal transport chain, supporting local industries.

This flagship[75] topic aims to address all of the aspects above mentioned via the deployment of a fleet of inland waterway vessels.

Project results are expected to contribute to all of the following expected outcomes:

- Retrofitting existing diesel propelled vessels with fuel cells and electric propulsion systems will have become the state-of-the-art. The integration of hydrogen fuel cells, hydrogen storage and distribution (infrastructure, bunkering, piping, and on board and onshore) solutions, based on a Europe-wide, harmonised regulatory framework, has become daily business;
- Track record of technical, financial and environmental performance resulting from the deployment and operation of a fleet of inland waterway vessels;
- At least 10% of all vessels in operation (about 1,500) will be hydrogen fuel cell propelled, covering the whole territory of the EU inland waters, creating a market for about 500[76] tonnes hydrogen per day;
- Hydrogen propelled vessels will be allowed to sail all inland waters in the EU using standardised regulations, without the need for lengthy approval processes;
- The sector uses common systematic design and engineering methods to achieve integrated ship and power train refits and new build solutions, such that further standardisation of the power train components (modules) is accelerated, allowing the rapid deployment of these technologies across the fleet.

Project results are expected to contribute to all of the following objectives of the Clean Hydrogen JU SRIA:

[75] For definition of flagship see section 5.3. of the Clean Hydrogen JU Strategic Research and Innovation Agenda 2021 – 2027

[76] assuming an average consumption of 125 tonnes a year per vessel (reference 110m vessel with 1MW FC).

- Product design reaching type approval [number]: 15 in 2024 and 40 in 2030;
- PEMFC system CAPEX [€/kW]: 1,500 in 2024 and 1,000 in 2030;
- Maritime FCS lifetime [h]: 40,000 in 2024 and 80,000 in 2030.

Scope

First demonstrators funded by previous FCH-JU projects, as well as other projects in recent years, have primarily focused on the demonstration of technical feasibility of fuel cells on board inland vessels. A large-scale demonstration is now required to further the uptake of fuel cells and hydrogen in this sector. This flagship project should include:

- at least 5 inland vessels (retrofitting and/or new build), with FC power above 500kW and preferably at 1 MW scale;
- at least 2 vessel types;
- 2 vessels should operate for at least 2 years, and the others for at least 1 year;
- vessels that should be able to bunker hydrogen in at least 2 different ports;
- creating a corridor, connecting to hydrogen infrastructure, aligned with the TEN-T[77] network;
- preferably one vessel is a (self-propelled) hydrogen bunker barge, which can bunker vessels alongside while in transit, at anchorage, or at the pier;
- An overall plan for deployment (with different stages) that goes beyond the timeline of this project should be foreseen. The needs of support for later stages should be justified in view of closing the funding gap in a dynamic environment where hydrogen shipping becomes increasingly competitive with incumbent technologies.
- A detailed data monitoring strategy (with minimum parameters to be monitored) that would allow evaluate the overall financial, environmental and technical performance of each of the vessel to be deployed in the project in sufficient detail. Costs related to the monitoring equipment are eligible.

It is highly recommended that the project collaborates with other projects (e.g. RH2INE[78], GREENPORTS,[79] MAGPIE[80] and PIONEERS[81]) on bunkering and refuelling infrastructure to align interfaces and create a robust hydrogen bunkering infrastructure along the TEN-T.

The proposed hydrogen fuel cell electric powertrain and storage should be a modular and easy-to-scale solution, in order to reduce conversion time as well as design and development cost for future vessels. On the technology side, the project should result in:

- Fuel cell systems, hydrogen storage and hydrogen distribution components meeting the unique requirements of inland waterway navigation, including but not limited to corrosion, performance, lifetime, and safety;
- Fuel cell systems, hydrogen storage and hydrogen distribution components with type approval, to increase market acceptance and ensure safety under all conditions;

[77] https://transport.ec.europa.eu/transport-themes/infrastructure-and-investment/trans-european-transport-network-ten-t_en
[78] https://www.rh2ine.eu/
[79] https://greencportsproject.eu/
[80] https://cordis.europa.eu/project/id/101036594
[81] https://cordis.europa.eu/project/id/101037564

- The development of resilient value chains in order to provide high quality products and solutions suitable for long-term commercial operations;
- Solutions which preferably build upon the lessons learned in StasHH[82] and consider circularity by design for equipment and business models;
- Secure approvals/exemptions from regulating bodies resulting in general permission for hydrogen powered inland vessels to navigate European waterways.

The project should focus on converting those ship types that have the highest impact on emissions. Nevertheless, it is expected that the developed solutions are also applicable to other vessel types and should be adaptable to different operations and associated power and energy consumption profiles. System dimensioning and integration should therefore be based on representative measurement data, allowing for optimal operations and efficient fuel consumption. A systematic retrofit design approach should result in general guidelines or advice for retrofitting inland vessels.

In order to successfully integrate modular hydrogen-based solutions on a large scale and embed them in the EU inland navigation industry, the project should at least perform the following dissemination and communication activities:

- During the project, results should be disseminated to the inland navigation sector, including training, integration & operation manuals and procedures, to enable knowledge transfer resulting in capacity building and general acceptance of maritime hydrogen fuel cell technology which would initiate other hydrogen vessel projects;
- Show the impact achieved via a lifecycle assessment (vessel, technology and operation) comparing the conventional (original) and new (retrofitted) situations;
- Include shipowners, shipyards, ship designers, maritime system integrators, ship operators, port authorities and classification authorities and all key staff within these organisations that would be involved in operating these technologies on board and on shore;
- Contribute to setting the standard when it comes to rules and regulations for type-approval and technical documentation;
- Establish a link with Zero Emission Waterborne Transport co-programmed partnership (ZEWT) to ensure that technical knowledge (best practices) can be exported to the larger and more complex (e.g. sea going) vessels.

The HORIZON-JTI-CLEANH2-2022-02-11 and HORIZON-JTI-CLEANH2-2022-03-05 topics are highly complementary and synergies between the two should be sought by applicants.

The refuelling infrastructure and its associated costs are not in the scope of this topic. Applicants are therefore strongly encouraged to seek support from alternative sources of funding and/or financing and provide such additional plan to minimise the risk of the implementation of vehicles and associated infrastructure and maximize its impact.

Applicants are therefore encouraged to submit complementary proposals to Clean Hydrogen JU (for the deployment of the vessels) and to CEF-T (for the deployment of the refuelling infrastructure)[83].

[82] https://www.clean-hydrogen.europa.eu/projects-repository_en

[83] The Connecting Europe Facility (CEF) for Transport (CEF-T) work programme 2021-2023 has a 3-year rolling call running for the Alternative Fuel Infrastructure Facility, with deadlines every 6 months, https://ec.europa.eu/inea/en/connecting-europe-facility/cef-

Furthermore applicants may consider additional synergies with other Programmes (e.g. European Structural and Investment Funds, Recovery and Resilience Facility, Just Transition Fund, Connecting Europe Facility, Innovation Fund, Modernisation Fund, LIFE, etc.) and/or clustering with other projects within Horizon Europe or funded under other EU, national or regional programmes, or having loans through the EIB or other promotional or commercial banks; such synergies should be reflected in a financing structure and strategy describing the business model, including envisaged sources of co-funding/co-financing and in line with state-aid rules.

This topic is expected to contribute to EU competitiveness and industrial leadership by supporting a European value chain for hydrogen and fuel cell systems and components.

It is expected that Guarantees of origin (GOs) will be used to prove the renewable character of the hydrogen that is used. In this respect consortium may seek out the purchase and subsequent cancellation of GOs from the relevant Member State issuing body and if that is not yet available the consortium may proceed with the purchase and cancellation of non-governmental certificates (e.g CertifHy[84]).

Proposals should provide a preliminary draft on 'hydrogen safety planning and management' at the project level, which will be further updated during project implementation.

Activities developing test protocols and procedures for the performance and durability assessment of electrolysers and fuel cell components proposals should foresee a collaboration mechanism with JRC (see section 2.2.4.3 "Collaboration with JRC"), in order to support EU-wide harmonisation. Test activities should adopt the already published EU harmonized testing protocols to benchmark performance and quantify progress at programme level.

transport#:~:text=The%20Connecting%20Europe%20Facility%20(CEF,and%20upgrading%20the%20existing%20one.

84 https://www.certifhy.eu/

TC3-10-A: Development and optimisation of a dedicated Fuel Cells for Aviation: Development of dedicated stack (100s kW) with the objective of MWs full system

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of around EUR 20 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 20.00 million
Type of Action	Research and Innovation Action
Technology Readiness Level	Activities are expected to start at TRL 4 and achieve TRL 5-6 by the end of the project See General Annex B.

<u>*Expected outcome*</u>

The use of Fuel Cells enables the generation of electricity aboard the aircraft from hydrogen (stored in a dedicated tank) and oxygen (air) without any CO_2, NO_x, particles emission as the only by-products of the reaction are water and heat. Therefore, these technologies have the potential to strongly reduce aviation emissions & pave the way to climate neutrality. Additionally, they can drastically reduce the noise when compared to gas turbines, both when a/c moving (flight/taxi) and on ground/stopped (while operating non propulsive energy systems).

Depending on the power delivered, fuel cells can supply either non-propulsive systems (electrical anti-ice systems, electrical Environmental Control System, Green Taxiing) or propulsive systems (electrical engines and propeller).

Experience shows that aviation constraints (weight, altitude) will require specific technologies in order to meet necessary KPIs.

Project results are expected to contribute to all of the following expected outcomes:

- Preliminary design of fuel cell systems with high efficiency and high gravimetric power density, compatible with aeronautical specifications and constraints and
- The maturation of necessary sub-components for this system (stack, balance of plant components etc) up to TRL5.

At the end of the project, performed lab and ground tests should have proven concept feasibility. The technologies will then be further matured under the support of the Clean Aviation partnership, embedded and integrated in a specified architecture for demonstrations.

Project results are expected to contribute to all of the following objectives of the Clean Hydrogen JU SRIA:

- FC module durability [h]: 20,000 in 2024 and 30,000 in 2030;
- FC system efficiency [%]: 45 in 2024 and 50 in 2030;
- FC system availability [%]: 95 in 2024 and 98 in 2030;
- FC system gravimetric index [kW/kg]: 1 in 2024 and 2 in 2030.

In addition to the KPIs above and when considering a system size of 1.5MW the proposal should also contribute to the achievement of the following:

- Power Densities @stack level > 3kW/kg in nominal power (and not peak power);
- Membrane Electrode Assembly > 1.25 W /cm2;
- Understanding of the ageing kinetics (= performances degradation in time) ;
- Environmental conditions: temperature, pressure, vibration and other area of interest (i.e. DO 160) compatible with aircraft environment;
- Demonstration fully answers the qualification needs.

The stack to be developed under this topic should be compatible with the requirements of the Clean Aviation Partnership SRIA in order to be implemented in ground and in-flight demonstrations scheduled within Clean Aviation partnership.

Scope

The technology (Proton Exchange Membrane Fuel Cell) that is emerging from the automotive industry through car manufacturers is of interest for aeronautic industry, but some issues are still to be solved (hydrogen storage and distribution from the tank to the fuel cell system are not considered here)

- The power of the fuel cell systems coming from the automotive industry is usually limited roughly to 100kW. Aviation needs are more in the range of 1 to 5MW depending on the size of the aircraft and/or the systems to supply with power (propulsive or non-propulsive). Development of 250 kW FC stack and scalability of FC system and components for an at least 1.5 MW module seems thus compulsory in order to allow aircraft application. This target is moreover clearly defined in the Clean Aviation SRIA;
- The stacks available today are not adapted to the environment in which they will have to operate: temperature ISA-35, pressure 0,2 bar (45 kft), vibrations, etc;
- The requested power is not achievable with only one stack. The following should be defined:
    - The optimal size of the stack;
    - The architecture of multi-stack systems.
- The cost of the technology needs to be reduced. Sizing a unitary stack of a reasonable amount of power will ease its integration in different size of aircraft and for propulsive and non-propulsive systems. This will increase the numbers and ease cost reduction;
- The lifetime of the fuel cells should be increased;
- Safety issues shall be considered right from the start. The means of compliance in order to answer to qualification/certification needs are not available. The certifications rules should be created/adapted.

Proposals should target a fuel cell system with a power density > 1.5kW/kg at a power level of at least 1 MW. The goal is to bring the technologies and sub systems to TRL5 at the end of the project, with lab and ground tests in a relevant environment.

This topic is crucial regarding the commercialization of FC Systems in aviation.

The integration of the full system into the aircraft needs to be considered and anticipated but is not the key focus and will be dealt with in a separated Work Programme. In the frame of Clean Aviation Partnership, an open call is expected to be launched to cover system integration and demonstrations.

Proposals should tackle the following aspects:

Requirements & specification

- Define a system compatible with aircraft (A/C) environment and constraints (safety, durability, availability, temperature, pressure);
- Define architecture to optimise weight and adequation to safety requirements. A system requirement and a high-level architecture optimum should be defined and agreed early in the project;
- Derive necessary technological bricks to be matured up to TRL5.

Fuel cell stack subsystem

- Increase the power density of the stack, by optimising designs through several means, for example but not exhaustive: lightweight metal substrates, high performance Membrane Electrode Assembly (MEA)/flow field combination, optimised stack compression system;
- Define and design stack architectures (i.e.: liquid cooled / 2-phase cooled). Separate paths may be explored;
- Increase the operating temperature of the stack and its capability to support larger inlet/outlet cooling temperature ranges, without compromising its lifetime;
- Analyse the robustness of the fuel cell stack to contaminants or other pollution source of the membrane;
- Reduce pressure losses over the stack, especially on the cathode, to balance stack performance versus system performance.
- The stack to be developed under this topic should be compatible with the requirements of the Clean Aviation Partnership SRIA in order to be implemented in ground and in-flight demonstrations scheduled within Clean Aviation partnership.

Balance of Plant (BoP) subsystem

- Define and resize anode and cathode BoP for stack regulation. BoP architectures may differ depending on stack architecture;
- Define a lightweight and robust stack monitoring system, easy to install and repair.

Besides, great care should be taken to the fuel cell interfaces, which will impact the trade off and overall system benefits:

Thermal management subsystem

- Fuel cell stack thermal management is key and should be analysed.
- Proposals will also have to cope with preliminary design of stack heat management. The realisation of fuel cell system driven aviation belongs from the maturity and

understanding of fuel cell system components and behaviour in aircraft environment. Based on stack developments scheduled in the first phase of the project, a focus on fuel cell system behaviour at continuous (more than 15 minutes) max power operation is strongly encouraged, so that dedicated heat management bricks will have to be developed. The technology drivers, components and behaviours which will be functionally upgraded can be (non exhaustive list): cathode air supply, intercoolers HEX, cathode humidifier, anode recirculation, relative humidity sensors, stack cooling pump, stack cathode and cooling flow pressure drop. Major focus will be (on at least a 300kW electric FC unit) the integration, debug and test of a FC module at max constant cooling temperature under A/C conditions. An additional focus will be the thermal optimization of the cooling system and controls during major load changes.

Air supply subsystem

- Define the air supply subsystem adapted to high altitude conditions (high compression rate and efficiency) and propose potential technological bricks in order to ensure this function: air inlet, filter, compressor and turbine, intercooler, humidification system, cathode recirculation, water separation, water management, air exhaust, piping and tubing, valves, temperature management, flow measurement and associated control.

Other hydrogen sub systems (storage, distribution) are outside of the scope of this topic. Proposals may include activity for the test bed development for FC testing in simulated A/C applications, and the development of relevant test protocols for performance and lifetime assessment for A/C load and operating environment profiles.

Activities developing test protocols and procedures for the performance and durability assessment of electrolysers and fuel cell components proposals should foresee a collaboration mechanism with JRC (see section 2.2.4.3 "Collaboration with JRC"), in order to support EU-wide harmonisation. Test activities should adopt the already published EU harmonized testing protocols85 to benchmark performance and quantify progress at programme level.

[85] https://www.clean-hydrogen.europa.eu/knowledge-management/collaboration-jrc-0_en

TC3-10-B: Development and optimisation of a dedicated Fuel Cells for Aviation: disruptive next-gen high temperature Fuel Cells technology for future aviation

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of around EUR 5.00 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 5.00 million
Type of Action	Research and Innovation Action
Technology Readiness Level	Activities are expected to start at TRL 2 and achieve TRL 4 by the end of the project. See General Annex B.

Expected outcome

The use of Fuel Cells enables the generation of electricity aboard the aircraft from hydrogen (stored in a dedicated tank) and oxygen (air) without any CO_2, NO_x, particles emission as the only by-products of the reaction are water and heat. Therefore, these technologies have the potential to strongly reduce aviation emissions & pave the way to climate neutrality. Additionally, they can drastically reduce the noise when compared to gas turbines, both when aircraft is moving (flight/taxi) and on ground/stopped (while operating non propulsive energy systems).

Depending on the power delivered, fuel cells can supply either non-propulsive systems (e.g electrical anti-ice systems, electrical Environmental Control System, Green Taxiing, etc) or propulsive systems (electrical engines and propeller).

Experience shows that aviation constraints (such as weight, altitude etc) will require specific technologies in order to meet the necessary KPIs.

Project results are expected to contribute to the following expected outcomes:

- The maturation of necessary Low TRL new generation of fuel cell technology, operating higher than 120°C (constant operation) to unlock thermal management issues for high power systems;
- Demonstration of the developed technology in lab test conditions (single cell or short stack).

At the end of the project, performed lab tests will have proven concept feasibility. The technologies will then be further matured in Clean Aviation Programme, embedded and integrated in a specified architecture for demonstrations.

Project results are expected to contribute to all of the following objectives of the Clean Hydrogen JU SRIA:

- FC module durability [h]: 20.000 in 2024 and 30.000 in 2030;
- FC system efficiency [%]: 45 in 2024 and 50 in 2030;
- FC system availability [%]: 95 in 2024 and 98 in 2030.

In addition to the KPIs above and when considering a system size of 1.5MW the proposal should also contribute to the achievement of the following:

- Fuel cell Gravimetric index @system level > 1.5 kW/kg nominal power, under nominal aviation environmental conditions. Note: For computation, the following “system” definition is proposed: Fuel Cell stack + Anode & Cathode BoP (incl. by-products management) + Thermal Management BoP (excl. Heat exchanger);
- Fuel cell Gravimetric Index @stack level > 3 kW/kg in nominal power (and not peak power);
- Power density @ Membrane Electrode Assembly > 1.25 W/cm^2;
- Ageing kinetics (= performances degradation in time) is understood;
- Environmental conditions: temperature, pressure, vibration and other area of interest (Ie DO 160) compatible with aircraft environment.

Scope

The technology (Proton Exchange Membrane Fuel Cell) that is emerging from the automotive industry through car manufacturers is of interest for aeronautic industry, but some issues are still to be solved (hydrogen storage and distribution from the tank to the fuel cell system are not considered here):

- Aviation needs are in the range of 1 to 5MW depending on the size of the aircraft and/or the systems to supply with power (propulsive or non-propulsive). This target is clearly defined in the Clean Aviation SRIA[86]. Such power level requires capability to dissipate almost the same power of heat, in a dedicated thermal management system;
- Current fuel cell technologies developed by automotive industry operate lower than 100°C at constant operation, which means that fuel cell thermal management system will have to evacuate a large amount of power with a low-grade heat due to FC low temperature;
- Thermal management and especially heat dissipation using a low-grade heat have a massive impact on aircraft performance: aircraft drag increase implies to boost aircraft propulsive system sizing (leading to manage more heat) and requires more energy for the same mission (leading to take on more fuel, and therefore to boost aircraft propulsive system);
- Fuel cell operating temperature increase (120°C +) would significantly help to reduce thermal management effect on aircraft flight performances, and unlock fuel cells applications for high power generation systems;
- Current developed High Temperature PEM-FC technologies (Phosphoric acid doped PBI-based MEAs for instance) are not at the expected level of performance for aeronautic target.

Proposals should target a disruptive 120°C+ constant operating temperature fuel cell technology with the same performances as current state-of-the-art low Temperature PEM technologies.

The integration of such a new fuel cell technology into an aircraft fuel cell system needs to be considered and anticipated but is not the scope of this topic.

[86] https://www.clean-aviation.eu/sites/default/files/2022-01/CAJU-GB-2021-12-16-SRIA_en.pdf

Proposals should address the following aspects:

Requirements & specification

- Early in the project, define a projected fuel cell stack using this disruptive fuel cell technology compatible with aircraft environment and constraints (safety, durability, availability, temperature, pressure);
- Define disruptive MEA of this technology specification. Disruptive MEA requirement and a high-level MEA architecture should be defined and agreed early in the project;
- Derive necessary technological bricks to be matured up to TRL 4.

MEA architecture, global consistency and performance

- Define a global MEA architecture by considering the interactions between all the components, layers and interfaces of a MEA: previous development of a disruptive MEA for automotive applications highlighted the need to take into account the global architecture of this component. High performance materials assembly do not meet the expected characteristics (performance, durability) of each component of a MEA taken individually. The overall architecture definition is the key for the development of an efficient MEA;
- Increase the kinetics of the Oxygen Reduction Reaction (ORR), main limiting reaction for PEM MEA;
- Design and develop an efficient electrolyte-catalyst interface to optimize the electrochemical active area;
- Design and optimize the Gas Diffusion Layer (GDL), Micro Porous Layer (MPL) and electrode interfaces to facilitate reactants and products management and ensure good electrical properties;
- Eco-design of the MEA has to be taken into account.

Proton or anion electrolyte technology

- Design a fuel cell technology working at 120°C+ (constant operation);
- Design an electrolyte technology with high proton or anion conductivity and no electrical conductivity;
- Define an electrolyte technology with low gas permeability;

Electrodes

- Design electrodes working at 120°C+ (constant operation);
- Design and optimize a cathode to improve ORR kinetics;
- Define and optimize the catalyst loading for Hydrogen Oxidation Reaction (HOR);
- Optimize catalysts support to improve electrochemical active area on both electrodes.

Gas diffusion layer

- Design GDL working at 120°C+ (constant operation);
- Design and optimize GDL composition and structure to efficiently transport and evacuate reactants from the bipolar plate channels to the electrodes, especially on cathode side where the oxygen transport to the catalysts has a major impact on

performances at high current densities;

- Optimize electrical conductivity of GDL;
- Design and optimize GDL with an efficient water management at 120°C+.

In addition, great care should be taken to strength, durability of the MEA, and transient start-up / shut down mode. In particular proposals should address the following:

<u>MEA strength</u>

- Design a MEA able to work with different pressures between anode and cathode;
- Design a MEA with high mechanical resistance.

<u>MEA Durability</u>

- Design a MEA with a durability > 20,000 h.

<u>Start and stop operations</u>

- Design a MEA able to undergo start and stop operations with limited degradation rate;
- Define a MEA able to start at cold temperature.

Proposals may include activity for the test bed development for FC testing, and the development of relevant test protocols for performance, lifetime assessment and operating environment profiles.

Activities developing test protocols and procedures for the performance and durability assessment of electrolysers and fuel cell components proposals should foresee a collaboration mechanism with JRC (see section 2.2.4.3 "Collaboration with JRC"), in order to support EU-wide harmonisation. Test activities should adopt the already published EU harmonized testing protocols[87] to benchmark performance and quantify progress at programme level

[87] https://www.clean-hydrogen.europa.eu/knowledge-management/collaboration-jrc-0_en

TC3-11: Development of specific aviation cryogenic storage system with a gauging, fuel metering, heat management and monitoring system

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of around EUR 10.00 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 10.00 million
Type of Action	Research and Innovation Action
Technology Readiness Level	Activities are expected to start at TRL 1 achieve and TRL 3 by the end of the project (CFRP[88]). Activities are expected to start at TRL 2 achieve TRL 4 by the end of the project (system). See General Annex B.

<u>*Expected outcome*</u>

To fulfil the ambitions of a commercial zero emission aircraft a liquid hydrogen (LH_2) fuel storage system is needed. In the first phase of Clean Hydrogen (2022-2025) two functional demonstrators shall be built. The demonstrators shall be in the range of 50 kg – 150 kg LH_2 capacity due to technical objectives and the available budget. Objectives of the project are the design and development of a lightweight LH_2 tank (demonstrator 1), and the integration of the storage system for a safe function and operation of a LH_2 tank on board of an aircraft (demonstrator 2). This local operation is not in the scope of this topic.

Demonstrator 1: The LH_2 tank will be used to address the need of a lightweight vessel. So, the demonstrator purpose is everything around the material selection (e.g. fibre reinforced materials) for the tank itself, liner and its insulation and the manufacturing of such a lightweight liquid hydrogen aircraft storage tank.

Demonstrator 2: The LH_2 tank will be used to validate the operation of such a storage including design and integration of components needed for a safe function (filling, structural health monitoring, overpressure, thermal management, boil off, sloshing, vaporising depending on a system safety analysis).

Project results are expected to contribute to all of the following expected outcomes:

- The demonstrators will be used to develop and validate computational models addressing static and dynamic behaviour (sloshing) as well as component sizing capabilities;
- System models of the operational behaviour will be developed and validated on the basis of hydrogen by operating and testing these demonstrators. The system simulation should cover the static and especially the transient cases with the interaction and fluid motion of liquid hydrogen (sloshing) and thermodynamic environment in the tank. In fact, in space applications the pressure drop induced by these types of interactions is well known and accounted for in the cryogenic tank

[88] Carbon Fibre Reinforced Polymer

design. The models will be used for functional analysis with failure hazards assessment, system safety analysis and common mode analysis of the system;

- The storage vessels and associated components should withstand defined normal static and failure fatigue load cases as well as the demanding environmental (including shock & vibration) and reliability requirements associated with commercial aviation (DO160, DO178, DO254). At the same time the hydrogen storage design and its installation should account for thermal deformation as well as pressure and temperature fluctuations during operation and filling at a delta temperature of ~300 K;
- The vessel (demonstrator 1) is required to store hydrogen safely at cryogenic temperatures for extended durations, with low boil-off quantities (see KPI) as well as superior gas barrier properties. This requires insulation technologies that are durable and lightweight, as well as liner and tank wall concepts with low gas permeability;
- Vacuum technologies shall also be studied and matured in order to fulfil the aircraft operation needs;
- Adequate safety precautions have to be implemented, which are covered by a secure design together with measurement and monitoring sensors and detection system;
- Necessary non-destructive testing and other inspection methods are needed and have to be developed and validated, because also the build and acceptance of such a storage has to undergo specially defined qualification tests. Due to budget reasons, this will not be part of this road map.

Project results are expected to contribute to all of the following objectives of the Clean Hydrogen JU SRIA:

- Tank gravimetric efficiency [%weight]: 16 in 2024 and 35 in 2030
- LH_2 tank capacity [kgLH_2]: 50-150
- Dormancy: >24 hours
- Venting rate: < 2%/day
- Filling rate: 300-500 kg/h (for analysis 5 t/h)
- Boil-off : < 2%/day after dormancy
- Maximum diameter: < 1 m (for analysis <3m)
- Minimum operating pressure: 1 bar (pump fed) – 3 bar (pressure fed)
- Maximum operating pressure: 3 bar (pump fed) – 8 bar (pressure fed)
- Insulation Vacuum: 1*10^-5 mbar

Scope

Proposals should focus on the development of an aerospace applicable liquid hydrogen storage system. There are various thermal, mechanical, safety and system integration challenges associated with this. Compared to kerosene in the wing, hydrogen storage leads to additional mass for the aircraft and requires additional space (LH_2 has 4 times the volume compared to kerosene at iso-energy content). Therefore it has a significant impact on the overall energy required for a mission due to both weight and volume with drag penalty.

Today's hydrogen tanks for storing liquid hydrogen in aerospace are mostly made of metal. For space application this solution is still valid, because of power available, non-reuse and costs. But having in mind commercial aviation, the focus should be on enhancing the metal tank and piping performance while designing a LH_2 storage system made of light carbon fibre reinforced materials. Using these components, a significantly improved gravimetric index for the whole storage system can be achieved. The drawback of using these materials is that the laminate quality or laminate architecture are of particular importance for permeability. Different test specimens, different semi-finished products made of glass, carbon, fibres with polymer or metal matrix, different additives, liners and architectures as well as coatings have to be considered. In addition, a selection of adhesives has to be made for use in cryogenic environments.

Besides the material selection and definition and control of the manufacturing process other aspects of the function and safe operation of a liquid hydrogen storage should be taken into account. The pressure and temperature of the LH_2 should be monitored to validate feed and fuel gauging functions under flight accelerations. The analysis of dynamic loads as a result of fuel sloshing should be addressed numerically and experimentally, as well as the pressure development in the tank due to the interaction of the sloshing hydrogen and the thermodynamic environment in the tank. The design solution should address the changing pressure by either active or passive means (e.g. active pressurisation control or passive anti-sloshing devices), to ensure safe operation of the engine feed systems.

A hydrogen content control and gauging system is required to provide accurate data on mission fuel throughout the flight, minimising unusable fuel and meeting all applicable airworthiness regulations. The structural integrity of the hydrogen tank has to be monitored by structural health monitoring (SHM), which can detect and locate damage. The system shall manage both normal and failed system states safely. Wireless and low energy systems shall be investigated to maximise safety and maintainability. The tank should have means to safely manage overpressure cases by a venting system to minimize risk of ignition and the impacts of cryogenic temperatures.

For operation the LH_2 evaporation and gas warm-up requires a considerable amount of energy. It has to be investigated how the thermal load will be injected into the storage with a focus on transient behaviour and start-up procedures. The hydrogen fuel tank should be able to facilitate applications of hydrogen burn engines as well as hydrogen fuel cell-based powertrains with minor adaptations only, permitting for either centralised boil off or distributed boil off management.

Considerations to the refuelling interface should be given, but the interface it-self is out of scope of this topic. Boundary conditions for this refuelling consideration include:

- Aircraft refuelling at a rate of approximately 5 tonnes/hour with means to refuel a cold or a warm vessel
- The cryogenic fuel will be distributed from one, or multiple tanks in the aircraft to an end user system.
- A standard coupling as an interface to refill aligned or adapted as well with other mobility sectors that allows a safe, reliable operation by the ground staff.

The gained experiences on the two storage demonstrators will be used in phase 2 (2026-2030) to obtain and define the certification regulation of commercial aviation hydrogen storages. Furthermore, in phase 2 (2026-2030) larger tanks have to be developed to become flight worthy.

TC4-01: Design and industrial deployment of innovative manufacturing processes for solid oxide fuel cells systems and fuel cell components

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of around EUR 7.00 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 7.00 million.
Type of Action	Innovation Action
Manufacturing Readiness Level	Activities are expected to start at MRL 4 and achieve MRL 7 by the end of the project. See Call management and general conditions section.
Admissibility conditions	The conditions are described in General Annex A. The following exceptions apply: The page limit of the application is 70 pages.
Eligibility	The conditions are described in General Annex B. The following additional eligibility criteria apply: At least one partner in the consortium must be a member of either Hydrogen Europe or Hydrogen Europe Research. The maximum Clean Hydrogen JU contribution that may be requested is EUR 7.00 million – proposals requesting Clean Hydrogen JU contributions above this amount will not be evaluated.
Legal and financial set-up of the Grant Agreements	The rules are described in General Annex G. The following exceptions apply: Purchases of equipment, infrastructure or other assets used for the action must be declared as depreciation costs. However, for the following equipment, infrastructure or other assets purchased specifically for the action (or developed as part of the action tasks): manufacturing equipment and tooling, costs may exceptionally be declared as full capitalised costs.

Expected outcome

Fuel cells offer the highest electrical efficiency for conversion of chemically stored energy. They can significantly contribute to an efficient use of produced hydrogen carriers and to the reduction of overall CO_2 emissions. The Clean Hydrogen Joint undertaking has a set a vision to reach for 2030 accumulated fuel cell installed power of >2.5 GW with total production rates >500 MW/year. Cost reductions have been achieved as part of the FCH 2 JU but additional reductions are needed to increase the market penetration of fuel cell solutions. The stacks are still the main cost driver for the fuel cell system, additional cost reductions can be achieved through high quality level and increased automation of stack manufacturing. One of the objectives of the Clean Hydrogen Partnership is to reach stack manufacturing costs (solid oxide) of ≤800 €/kW at annual production volume of single manufacturing line of at least 100 MW.

Project results are expected to contribute to the following expected outcome:

- Cost reduction of fuel cell systems by automation of specific and time-consuming manufacturing steps;
- Increased fuel cell systems and component manufacturing capacity of European industry establishment of a European supply chain of specialised solid oxide cells (SOC) manufacturing equipment;
- Improved sustainability of the manufacturing processes and products; significantly reduce or reuse waste and lower the energy and carbon footprint.

In addition, project results are expected to contribute to at least one of the following specific (quantified) outcomes:

- Automation of stack assembling and sealing with yield >90%;
- Automation of cell manufacturing with integrated quality control measured and yield >95%;
- High speed interconnect manufacturing and coating within the specification of stack manufacturer;
- Time-efficient and inexpensive quality control procedures suitable for inline inspection.

Project results are expected to directly contribute to all of the following objectives of the Clean Hydrogen JU SRIA Pillar 3, Hydrogen End Uses: Clean heat and Power:

- reduction of CAPEX of stationary fuel cells of all sizes and end use applications. The target is to reach stack production cost <800 €/kW at production capacity of 100 MW/year;
- support of development of processes suitable for mass manufacturing.

In addition, due to high synergies in manufacturing of SOFC and SOEL stacks this topic will also contribute to the following objectives for pillar 1 Renewable Hydrogen Production

- reduction of electrolyser CAPEX below 520 €/kW;
- increasing scale of deployment and series production for steam electrolysis.

<u>*Scope*</u>

The manufacturing of solid oxide fuel stacks and stack components according to state-of-the-art is performed by a large amount of human force. The degree of automation for cell and interconnect production reaches 30% and for stack manufacturing stays below 15%, however the target values of 50-65% for 2026 should be reached to enable the envisaged high-volume production. The manufacturing processes reached reasonable yields but often are historically developed and not designed for automation. Re-design of critical steps for mass-production manufacturing, development of automation of human workforce and time-consuming manufacturing processes in stack and/or components manufacturing and quality control are entirely addressed by present call.

Support under the FCH 2 JU managed to create a track record of projects[89] (HeatStack, SOSLeM, qSOFC) directed towards cost-effective manufacturing of components, stacks and systems. The development in the HeatStack project showed the potential to reduce the production cost of the sealing in the SOFC stack by 90%. The glass sealing inside the stack is estimated to be responsible for about 10% of the stack production costs. In addition, the qSOFC project contributed considerably to solid oxide stack development by enhancing manufacturing and quality assurance at key parts of the all-European stack manufacturing value chain. This project concluded that a stack cost level of 1000 €/kW is achievable at production levels of 15 MW/year. The specific improvements include: increase speed of cell production, interconnect manufacturing and stack conditioning processes. Finally, the SOSLeM project helped to create a new stack production plant, making the manufacturing process cheaper, cleaner and smarter by introduction of automated laser welding, simplification of the design for automated component stacking and end-of-line testing.

The scope of this topic is to adapt and develop manufacturing processes on a prototype tool that can then serve several manufacturers. It aims at establishing a European supply chain of specialised SOC manufacturing equipment that can be adapted by several manufacturers, or even exported to overseas markets in scenario where European technology is licensed for local production in overseas territories. The supply of equipment is a market opportunity on its own, though the proximity with the domestic manufacturers supports their ability to stay ahead of competition.

The design for manufacturing and automation should be considered along the whole value chain of stack production. The joint effort on several subjects such as component supply chain, process automation, stack and system manufacturing are needed to address the challenges of cost reduction by automation and upscaling.

Proposals should address the following:

- Proof of concept, design and adaptation of approaches from automation industry, whose implementation for the production of cells, stack components or stacks, could significantly improve production process for selected critical manufacturing processes should be considered;
- The demonstration of two or more automated production steps, initially performed manually with considerable time effort, should be performed. The ones with the greater impact on costs and waste production should be considered preferably;
- Archetype for the mass production of FC, definition of a virtual production process with a high degree of automation (at least 75%) and implementation of mature methodologies known from automation industry for target production volume of at least 100 MW/year (from 20,000 to 100,000 units/year depending on nominal stack power) utilising the developed automated production step should be planned;
- Techno-economic assessment and demonstration of stack output of 100 MW/year (corresponding from 20,000 to 100,000 units/year depending on single stack power) resulting in target manufacturing costs <800 €/kWel should be provided;
- Digital concept for complete component tracking and continuous validation of virtual twins for component and/or stack manufacturing should be considered;
- Circularity assessment in technology / prototypes development should be provided;

[89] https://www.clean-hydrogen.europa.eu/projects-repository_en

- The IPR on the manufacturing tool and equipment is to be with the automation company, in order to enable other manufacturers to benefit from the experience and to strengthen the overall sectors competitiveness in Europe.

At least one of following manufacturing processes should be addressed:

- Sealing process of high temperature solid oxide cells: design, implementation, test of automated sealing stations for stack manufacturing with easy stack connection-disconnection and integrated cost-effective sealing process control and quality assessment for 20,000 to 100,000 units/year;
- Ceramic cell production for solid oxide cells. Automated ceramic cell production, which cover the areas of raw material quality control, semi-products manufacturing, layer deposition technology, sintering (i.e. tunnel furnace), handling of green and sintered parts and quality monitoring able for a cell production capacity from 1.5 to 4 million units/year;
- High speed bipolar plate production and coating, production related quality monitoring and comprehensive testing methods using artificial intelligence and machine learning algorithms, if required, designed for cell production capacity from 1.5 to 4 million units /year.

By the end of the project the production process utilising automated steps, initially performed by manual working force, should be successfully demonstrated resulting in considerable (>60%) reduction of production time and costs of corresponding manufacturing steps.

Activities are expected to start at MRL 4 and achieve MRL 7 by the end of the project.

The topic is not intended to cover the establishment of pilot or full-scale manufacturing plants, or basic research on new materials, or fundamentally new cell and stack designs. The focus of the project is to demonstrate, in an industrial environment, the possibility of automating the most expensive processes, today performed manually or with technologies not suitable for the achievement of the production objectives described in the topic. The project should close the gaps for design and supply of automated turn-key equipment for production of stacks and/or stack components.

Consortia should include industrial partners responsible for: automation, quality control and stack or stack component manufacturing. A leading role is expected to be taken by the automation/equipment manufacturer/s in the consortium. The industrial partners should be supported by research institutes, which focus on but not limited to: relevant manufacturing technologies, failure analysis in manufactured components, implementation of non-destructive testing (NDT) and novel quality control methods, artificial intelligence and machine learning algorithms for quality management, post-operation analysis of stacks and components.

Consortia are encouraged to explore synergies and cooperation with Made in Europe partnership (Cluster 7) as well as to seek for additional national funding.

This topic is expected to contribute to EU competitiveness and industrial leadership by supporting a European value chain for hydrogen and fuel cell systems and components.

Proposals are expected to address sustainability and circularity aspects. In particular, circularity and sustainability by design concepts should be holistically considered towards the whole technology chain.

Proposals should provide a preliminary draft on ‘hydrogen safety planning and management’ at the project level, which will be further updated during project implementation.

TC4-02: Ammonia powered fuel cell system focusing on superior efficiency, durable operation and design optimisation

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of around EUR 4.00 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 4.00 million.
Type of Action	Research and Innovation Action
Technology Readiness Level	Activities are expected to start at TRL 3 and achieve TRL 5 by the end of the project. See General Annex B.

<u>*Expected outcome*</u>

Fuel cells are known as the most efficient energy conversion outperforming conventional power sources. Hydrogen and natural gas-powered fuel cell systems have reached high-level technology readiness levels (TRL) and demonstrated reliable durability in operation. However, today's roadblock preventing fuel cells from winning a greater share of the power market is the lack of availability of affordable, carbon free, and easily transportable fuel. Against this background ammonia shows huge potential as hydrogen carrier. Liquid ammonia - with twice as much hydrogen as liquid hydrogen by volume and carbon-free formulation – unleashes a new dimension in fuel cells applications. Ammonia as a fuel in fuel cells can provide a great impact on de-fossilisation in all power consuming sectors of the global economy. A use of ammonia for industrial business-to-business (B2B) prime power and long-term backup power production provides opportunity for further decrease of carbon dioxide emissions in regions having easy access to this fuel.

Project results are expected to contribute the following expected outcome:

- support European industry across the whole value chain in the development of the next generation power appliances utilising ammonia as a fuel;
- demonstration of high efficiency, fuel cell-based systems operated on ammonia as a means to provide new options for de-fossilisation of different energy sectors and facilitate establishing value chains between fuel cell industry and existing players in industrial markets;
- contribute to the decarbonization of autonomous power systems operated on a liquid carbon-free fuel e.g. digital data transmission sector, such as telecom (5-15 kWe), communication support for critical infrastructures (up to 5 kWe), energy supply (up to 10 kWe) for early warning systems (i.e. hazardous climate-related event transmitters. These market opportunities represent a suitable stepping stone to deploy fuel cell systems with high efficient energy conversion rate of ammonia fuel to power within a reasonable timeframe;
- Set the basis for the development of large power generators in the 100 kW and MW scale for e.g. harbours where ammonia is available as commodity already today. Green ammonia figures as a candidate to become the future standard fuels in

maritime applications;

- Gain and transfer knowledge and experiences to the maritime providing sector.

Project results are expected to directly contribute to all of the following objectives of the Clean Hydrogen JU SRIA Pillar 3, Hydrogen End Uses: Clean Heat and Power:

- Prepare and demonstrate the next generation of fuel cells for stationary applications able to run under (renewable) hydrogen-rich fuels whilst keeping high performance;
  - Target: Electrical efficiency of the system ≥50%; total system power degradation ≤3% at nominal power measured over at least 1,000 hours of continuous operation; availability of the system ≥90% during whole testing period gathering ≥3,000 operating hours; fuel cell system able to operate at partial loads;
- Fuel cells operating on alternative (renewable) fuels; Target: 5-15 kW fuel cell system operating with green ammonia including operation at partial load;
- New technologies and components to reduce costs and improve flexibility in operation. Target: fuel cell system costs ≤5,000 €/kWe for 100 MW annual production.

<u>*Scope*</u>

The scope of this topic is to design, manufacture and validate in relevant environmental an ammonia fuelled fuel cell system with a total electrical power output of 5-15 $kW_{el.}$ The system should operate for at least 3,000 hours and be also validated for operation at partial loads.

The system requires innovative scientific and engineering solutions. The focus of research may include innovative fuel cell design and should include BoP components and integrated ammonia cracker, safe and durable operation. For system development proposals may use available fuel cell technologies. Fuel cell manufacturers should be part of consortia.

Balance of plant (BoP) components needed for ammonia-driven fuel cells determine overall efficiency and durability of the system and should be designed taking into consideration the following requirements:

- Ammonia cracker integration into the system without external power should allow a fully autonomous operation;
- System design and integration of BoP should enable to maximise heat recovery;
- System should demonstrate dynamic load and relevant operating conditions in respect to the intended application;
- Power consumption for internal needs should be minimised.

Proposals should address the following:

- System design and development utilising existing fuel cell manufacturing technologies;
- Development of ammonia-tolerant BoP components;
- Dynamic modelling of system performance;
- Identification of degradation mechanisms in fuel cells and BoP components (including ammonia purity and degree of ammonia cracking), and effect of operation parameters;

- Risk assessment of safety aspects in relation to the future certification of the system;
- Techno-economical assessment for a selected application;
- System operation / state of health monitoring;
- System operation with various grades of ammonia, including concentrations of ammonia in the feeding gas and impurities/contaminants;
- System–dynamic load and transient behaviour according to the end-user load profile(s) for selected application(s).

Consortia are expected to gather comprehensive expertise from the European research and industrial community. Participation of end user(s) for the selected system application is also expected.

Activities developing test protocols and procedures for the performance and durability assessment of electrolysers and fuel cell components proposals should foresee a collaboration mechanism with JRC (see section 2.2.4.3 "Collaboration with JRC"), in order to support EU-wide harmonisation. Test activities should adopt the already published EU harmonized testing protocols90 to benchmark performance and quantify progress at programme level.

[90] https://www.clean-hydrogen.europa.eu/knowledge-management/collaboration-jrc-0_en

TC4-03: Reversible SOC system development, operation and energy system (grid) integration

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of around EUR 5.50 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 5.50 million.
Type of Action	Research and Innovation Action
Technology Readiness Level	Activities are expected to start at TRL 3 and achieve TRL 5 by the end of the project. See General Annex B.

Expected outcome

Reversible Solid Oxide systems (rSOC) have a huge scope in the stationary energy sector because both power generation, in Fuel Cell operation (FC mode), and hydrogen production, in Electrolyser operation (EL mode), can take place within the same system. What this means is the CAPEX (Capital Expenditure) costs can greatly be reduced. Another key advantage with the rSOC technology is the possibility for sector coupling. This means rSOC systems coupled to industrial processes can help industries go down the zero emission or carbon neutral path.

Project results are expected to contribute to all of the following expected outcomes:

- Enable Renewable hydrogen production and its injection in the gas or hydrogen grid at a distributed level, offering new business models for hydrogen supply for gas and energy companies;
- Allow the balancing of power grids when excess renewable energy is flowing in, leading to new and attractive practices for electric power companies and new businesses;
- Enable localised storage of hydrogen in a micro-grid scenario. This would help in the development of new concepts for delivery of hydrogen for fuel cell vehicles (also off-road, construction machines etc.), similar to the concept of localised battery charging points;
- Pave the way for large (10 MW onwards in Fuel Cell Mode/30 MW in electrolyser mode) reversible solid oxide systems parks (similar to solar or wind parks). Such large parks will be capable of absorbing excess renewable energy and transforming it to renewable hydrogen and other useful fuels/chemicals in a green way.

Project results are expected to directly contribute to the following objectives of the Clean Hydrogen JU SRIA:

- For Pillar 3, ‘Hydrogen End Uses: Clean heat and Power: Improve flexibility of systems in operation in particular with reversible fuel cells;
- For sub-pillar 1 ‘Electrolysis’: Demonstrate the value of electrolysers for the power system through their ability to provide flexibility and allow higher integration of

renewables'.

In doing this the following KPIs should be addressed:

- Transient operation of the final system:
    - Number of switching cycles between FC & EL Modes – at least two per day;
    - Time for transition (in minutes) from one mode to another in the range of below 30 min.

- System Roundtrip efficiency – at least 38% (with hydrogen) or higher (with natural gas) for 2024. The efficiency should be computed for a configuration where the rSOC is connected to the gas grid which acts as supplier and receiver of the gas needed or produced;

- Degradation rate (quantified with combined FC & EL Modes) below 0.4% per 1,000 hours on stack level after 2024;

- Projected system capital cost below 6,000 EUR/kWe after 2024 and going down to 3,500 EUR/kWe by 2030. This refers to the overall reversible SOC system costs whose reference power is the nominal one in fuel cell mode.

This topic will also contribute to set the basis for solutions aiming at facilitating sector coupling and hence contributing to the objectives of the Hydrogen Valleys pillar.

<u>*Scope*</u>

Reversible solid oxide systems are expected to play a major role in future seasonal/periodical energy storage methods. Previous FCH JU projects[91] such as BALANCE, SElySOs, ECO and NewSOC have explored some of the most promising proposals with respect to systems, materials and process chains that are suitable when using a reversible solid oxide system. In BALANCE the concept of rSOC was the highlight and activities focussed on rSOC operation and implementation. The projects REFLEX and SWITCH also include rSOC at the core of their systems. In REFLEX, hydrogen is generated locally and re-used by the same system. The system can be operated in island mode or in electricity grid connected, no connection is made to the gas grid. SWITCH focuses on the continuous supply of hydrogen for industrial or mobility use. The rSOC at the heart of the systems provides the arbitrage of using either electricity or methane as source of hydrogen, according to the best available source at any moment. The SWITCH system can operate on methane from the gas grid although reinjecting hydrogen back into the grid is not foreseen at any moment. Moreover, other projects dealing with monitoring, diagnostics and control for SOC have provided a reference framework for the implementation of solutions that are able to guarantee optimal operation and durability of stack and BoP (Balance of Plant).

The current rSOC stacks/systems lack clear performance specifications when used on blends of natural gas and hydrogen. Therefore, still a large gap needs to be filled both at the system and cell/stack level that call for further research. Learnings and findings from the above projects should form the base for the investigations proposed in this topic.

The scope of this topic is to design and develop a reversible solid oxide system of at least 5 kWe in fuel cell mode and capable of absorbing at least 15 kWe in electrolysis mode. The solution developed should be validated in a relevant environment. Continuous operation of at least 3 months should also be demonstrated.

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91 https://www.clean-hydrogen.europa.eu/projects-repository_en

The reversible solid oxide system (rSOC) should be designed and developed to allow for:

- Full compatibility with the existing natural gas grid of today and the hydrogen grid of tomorrow in addition to the electricity grid. This will in turn contribute to achieving to the following major objectives i) transition from natural gas to hydrogen as an energy vector ii) decentralised energy production, iii) balancing the high variability of electric energy from renewables and iv) energy security;
- Connection to both the gas grid and the electricity grid. The gas for FC Mode operation will be taken from the gas grid and the hydrogen produced from EL Mode operation (with or without processing) will be fed back to the gas grid;
- Reinjection of gas/hydrogen into the gas grid. In the case of reinjection as hydrogen, local concentration monitoring and mixing with natural gas (diluting it) is of essence. The alternative option of performing co-electrolysis raises the challenge of collecting and storing CO_2 of sufficient purity for co-electrolysis operation. This can potentially be coupled to the storage of oxygen produced in the electrolysis mode. Proposals can adopt any of these approaches;

Addressing the issues above will help promoting a prosumer hydrogen-based stationary sector.

<u>Proposals should address the following at the system level:</u>

- A rSOC system capable of generating at least 5 kW_e in fuel cell mode and capable of absorbing at least 15 kW_e in electrolysis mode needs to be developed, in line with the KPIs mentioned in the expected outcomes;
- The concepts used in developing the system should allow scalability to higher powers not only by adding individual stacks but also by increasing the stack power;
- The system should be able to operate not only with 100% hydrogen as fuel but also with mixtures of hydrogen and natural gas in Fuel Cell mode. In Electrolysis mode the system should be able to operate either in steam electrolysis or co-electrolysis mode, depending on the best possible approach leading to compatibility with the gas grid;
- A functioning prototype of the system should be validated in a relevant environment. A mix of hardware and hardware in the loop components can be chosen, to demonstrate how the system would work when deployed in the real world. A set of suitable algorithms and logics should also be implemented in order to monitor, diagnose and control the system for optimal operation in both modes and during switching. Safe operating strategies and appropriate design maps for system operation should be addressed. Electrical load following in electrolysis mode is quite critical; hence, performance with respect to load following should be quantified in a suitable manner;
- The reversible solid oxide system should have a common set of BoP (Balance of Plant) for both modes of operation. This is to ensure that the CAPEX cost stays low. The downstream gas/chemical processing system is a separate system of its own and is not part of the rSOC system which is to be developed and tested.

<u>Proposals should address the following at cell & stack level:</u>

- On the cell level, either commercially available cells may be used, or electro-catalytic materials can be specifically engineered keeping reversible operation in mind. The cells should perform up to the current standards or higher and should meet the KPIs given above. The same should be replicated on the short stack and full stack levels. The cell should be able to operate at a current density of at least 1.5 A/cm^2 or higher in both modes of operation. Transient time during switching between modes should be quantified and kept low for practical operations;

- Appropriate State of health monitoring methods and monitoring tools should be developed and implemented which can predict performance degradation when cell is operated the two modes EL (with steam electrolysis and/or co-electrolysis) and FC (with several combinations of feeding mixtures);

  These methods and tools should be translated for use on stack level and implemented on the full system.

Proposals should also demonstrate how the solution developed would allow to create a synergy between the gas transmission system operator and electric transmission system operator. In addition proposals should develop and propose early business models targeting at energy companies including gas and power utilities.

Activities developing test protocols and procedures for the performance and durability assessment of electrolysers and fuel cell components proposals should foresee a collaboration mechanism with JRC (see section 2.2.4.3 "Collaboration with JRC"), in order to support EU-wide harmonisation. Test activities should adopt the already published EU harmonized testing protocols[92] to benchmark performance and quantify progress at programme level.

[92] https://www.clean-hydrogen.europa.eu/knowledge-management/collaboration-jrc-0_en

TC4-04: Dry Low NO_x combustion of hydrogen-enriched fuels at high-pressure conditions for gas turbine applications

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of around EUR 4.00 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 8.00 million.
Type of Action	Research and Innovation Action
Technology Readiness Level	Activities are expected to start at TRL 4 and achieve TRL 6 by the end of the project. See General Annex B.
Procedure	The procedure is described in General Annex F. The following exceptions apply: To ensure a balanced portfolio covering complementary approaches, grants will be awarded to applications not only in order of ranking but at least also to one additional project that is / are complementary, provided that the applications attain all thresholds.

<u>Expected outcome</u>

A significant reduction of atmospheric pollution and emissions of greenhouse gases from power generation can only be achieved by transitioning away from fossil fuels and by increasing the share of Renewable Energy Sources (RES). However, the volatility in power output introduced by increasingly large shares of RES in the future energy system represents a key challenge. In this context, gas turbines (GTs) are considered to be the most robust, mature and cost-effective technology especially for large-scale power generation and are bound to reinforce their role as guarantors of grid stability and reliability. In order to fulfil this role in line with the Paris Agreement's goals, power generation from gas turbines needs to be decarbonised. A convenient approach to achieve this is by blending increasingly higher fractions of hydrogen into natural gas – the gas turbines' conventional fuel.

Project results are expected to contribute to the following expected outcomes:

- Develop a portfolio of solutions of full-scale gas turbine combustors for decarbonised, dispatchable and flexible heat and power generation across different systems sizes; from distributed systems all the way to large scale power generation plants;
- Ensure a cost-effective and safe utilisation of hydrogen as gas turbine fuel, including issues related to social acceptance of hydrogen-fired power plants by local communities;

Project results are expected to directly contribute to the objectives of the Clean Hydrogen JU SRIA Pillar 3, 'Hydrogen End Uses: Clean heat and Power' on preparing gas turbines to run on 100% hydrogen, whilst keep conversion efficiencies and NO_x emission to acceptable levels. In particular the following objectives and related KPIs as included the Clean Hydrogen JU SRIA should be addressed:

- Allow substantial increase of hydrogen-firing capabilities of new or existing gas turbine combustion systems to volumetric Hydrogen fractions between 70% and 100%;
- Demonstrate emission-compliant operation, in line with emission limits set by legislation;
    - Target @ 70% vol H_2: <25 NO_x ppmv@15%O2/dry or 29 NO_x mg/MJ fuel
    - Target @ 100% vol H_2: <25 NO_x ppmv@15%O2/dry or 24 NO_x mg/MJ fuel
- Demonstrate operational (load) flexibility of gas turbines, within the standard specifications for natural gas operation, at all Hydrogen fractions (0-100%);
    - Target for maximum H_2 content during start-up of 20% volume H_2 in 2024 with a view to reach 100% volume H_2 for 2030;
    - Target for maximum efficiency reduction in H_2 operation of 10% points @70% Volume of H_2 for 2024 with a view to reach 10% points @100% H_2 in 2030;
    - Target for minimum ramp up rate of 10% load / minute @70% volume H_2 in 2024 with a view to reach 10% load / minute @100% H_2.
- Allow for a significant variability of the hydrogen fraction in natural gas, depending on the actual availability of hydrogen, which should be handled seamlessly by the gas turbine combustion system:
    - Target for handling H_2 content fluctuations of ±15% H_2 volume / minute in 2024 with a view to reach ±30% H_2 volume / minute in 2030.

Scope

The capability for gas turbines to operate on hydrogen-based fuels is a key future requirement to fulfil the target of CO_2-free power generation. Currently, the maximum volumetric hydrogen fraction, up to which commercially available gas turbines can be operated with, lies between 30% and 50% depending on the specific gas turbine class and type. Ongoing H2020 projects (HYFLEXPOWER[93], FLEXnCONFU[94]) are focusing on power-to-gas-to-power technologies and partly also address hydrogen combustion in gas turbines. They are focussing on the whole power-to-gas-to-power system and hence either on small GT sizes (12MW in HYFLEXPOWER) or target to demonstrate small hydrogen fractions (FLEXnCONFU). Consequently, significant technological advancements in the gas turbines' combustion systems are required to further reduce and ultimately eliminate natural gas from the fuel blend.

The peculiar thermodynamic and combustion properties of hydrogen (e.g. diffusivity, reactivity, flame speed etc.) pose new challenges towards the achievement of a stable combustion process. These challenges are greatly increased for hydrogen combustion at the high-pressure conditions, which are relevant for gas turbine operation.

The scope of this topic is to design and demonstrate in relevant environment a scaled and full-size combustion system, i.e, same geometry and fire power as finally installed in the gas turbine. It is expected that experimental investigation will be performed up to full-load condition at least on a single burner of the gas turbine, including the monitoring and control in case of new combustors as well as for retrofits. These combustion systems should be

[93] https://cordis.europa.eu/project/id/884229
[94] https://cordis.europa.eu/project/id/884157

capable of operating at full gas turbine pressure conditions with any concentration of hydrogen admixed with natural gas and focus on volumetric hydrogen contents between 70-100%, i.e. well beyond the capability of state-of-the-art commercial gas turbines.

Activities are expected to start at TRL4 and should foresee the necessary laboratory experiments and numerical modelling leading to the design and validation of a full-size combustion chamber. At the end of the project duration, the proposed and developed solutions should achieve TRL6 and be validated in a relevant environment.

In order to achieve the expected outcomes, the development of the combustion system development should have in mind the following constraints and present solutions to overcome the associated technical hurdles:

- Stable combustion properties of hydrogen-rich flames demonstrated in full-scale combustor hardware at high pressure gas turbine conditions and across the entire GT load. This includes static (no flame flashback) as well as dynamic stability (no thermo-acoustic instabilities)
- Ensure sufficiently high firing temperatures to maintain high cycle efficiency of the respective gas turbine class.
- Ensure ultra-low emissions of air pollutants, in particular those of nitrous oxides (NO_x)
- Development of solutions for a combustion system that is capable to overcome previously mentioned technical challenges without the use of diluents (e.g. nitrogen, steam dilution, etc).

Consortia are expected to include turbine manufacturers. It is also encouraged to seek the involvement of plant operators. In addition, proposals should demonstrate that they will have access to the infrastructure that will be necessary to undertake the full-size testing.

As there may be different means to address the aforementioned technical hurdles, the specific research activities should be clearly detailed in the project proposal. Preferably the topic will support complementary approaches for small to medium power industrial gas turbines (above 12 MW electric) and large heavy-duty gas turbines (above 200 MW electric).

CROSS-CUTTING

TC5-01: Public understanding of hydrogen and fuel cell technologies

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of around EUR 1.00 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 1.00 million.
Type of Action	Coordination and Support Action
Technology Readiness Level	n/a

<u>*Expected outcome*</u>

Public and consumer understanding and acceptance will play a critical role in the successful future adoption of hydrogen and fuel cell (FCH) applications, both in the residential and the transport sectors. As markets for FCH technologies develop, citizens may react in different ways to hydrogen policies and infrastructures in their countries, regions and cities, and consumers and end-users will decide whether fuel cell applications fit their circumstances. The transition to hydrogen therefore not only poses technological challenges; it also requires a better understanding and response to cross-cutting issues related to citizen and consumer understanding and acceptance as well as broader environmental, socio-cultural and political issues.

Project results are expected to contribute to some of the following outcomes:

- Understanding public perceptions and reactions to hydrogen and fuel cell technologies;
- Identification of the main individual-level determinants of public understanding and acceptance of FCH technologies;
- Enhancing involvement of citizens in the implementation of solutions contributing to the transition to hydrogen and fuel cells;
- Understanding the pathways to influence public opinion by analysis of the current depiction of FCH technologies in broadcasts, newspapers, and social media, and from this developing a public information strategy;
- Assessment of the specific role of the socio-economic and environmental impacts of FCH technologies in both the public acceptance of FCH technologies and informed decision-making.

Project results are expected to contribute to all of the following objectives of the Clean Hydrogen JU SRIA: (especially for Cross-cutting issues - Area: Education and Public Awareness):

- to raise public awareness and trust towards hydrogen technologies and their system benefits, through the provision of guidelines/good practices and various engagement activities such as general public conferences and workshops, brochures, public show rooms, e.g. museum displays; addressing and informing local authorities, certification bodies, first responders, etc.

Scope

The challenge for this topic is to further understand reactions and attitudes towards FCH technologies among citizens, consumers, and stakeholders in Europe for developing a comprehensive set of guidelines/good practices and engagement activities to increase public awareness and trust, supporting the mass uptake of FCH technologies in Europe. The successful proposal should generate empirical evidence regarding public attitudes towards FCH technologies in Europe. This knowledge will inform the future implementation of actions aimed at devising more effective ways of involving citizens and stakeholders in FCH related aspects and projects.

Activities should take into account the outcomes of the public tender launched in 2021 by the FCH 2 JU on the "public opinion survey and measures to be taken to overcome the challenges"[95] as well as previous and ongoing FCH projects and initiatives engaging the public, on previous social research on public attitudes and reactions to hydrogen and fuel cell technologies and specific social research initiatives on FCH technologies and applications such as the activities of the HYACINTH project[96] (FCH 2 JU, 2014-2017), facilitating the learnings from past and on-going experiences and successes for the development of the final guidelines/good practices and engagement activities.

Activities should focus on FCH technologies as a whole and should target the public and specific groups of stakeholders from sectors and territories for which the development and deployment of FCH technologies can play an important role.

Activities should include social research and public engagement activities, implemented in a significant number of Member States or associated countries, covering but not limited to EU-13 countries, such as world cafes, panel debates, focus groups, workshops, demonstrations, ‘hands-on’ events (e.g.: museum workshops), surveys, exhibitions, social media campaigns, etc. targeted at the public and relevant FCH stakeholders and coming from a collaborative, science-driven framework that involves social/sustainability scientists and FCH experts, scientists experts in popular science, scientific content editors, etc. as needed. Projects should provide a quantitative assessment of the impacts foreseen, providing the metrics and/or indicators to assess the impacts of the engagement activities towards the identified target groups.

The use of bridging tools (for instance, Social Life Cycle Assessment) to facilitate the connection between the technical and social dimensions and enable informed decision-making is encouraged. In this regard, the joint work between social sciences experts and experts in the entire FCH value chain, among others, should result in sound guidelines and materials for future FCH public engagement programmes, projects, and outreach activities.

A balanced overall coverage of EU countries should be sought. All categories of the population, including minorities, youth and the elder generation, as well as urban, peri-urban and rural areas, should be considered.

Activities should envisage links and synergies with existing platforms and/or projects on FCH technologies as well as means of collaboration with similar activities ongoing internationally.

Proposals are expected to contribute towards the activities of Mission Innovation 2.0 - Clean Hydrogen Mission. Cooperation with entities from Clean Hydrogen Mission member

[95] https://etendering.ted.europa.eu/cft/cft-display.html?cftId=8895
[96] https://www.clean-hydrogen.europa.eu/projects-repository_en

countries, which are neither EU Member States nor Horizon Europe Associated countries, is encouraged (see section 2.2.6.8 International Cooperation).

TC5-03: Safety of cryogenic hydrogen transfer technologies in public areas for mobile applications

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of around EUR 2.00 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 2.00 million.
Type of Action	Research and Innovation Action
Technology Readiness Level	n/a
Legal and financial set-up of the Grant Agreements	The rules are described in General Annex G. The following exceptions apply: Beneficiaries must, up to 4 years after the end of the action, inform the granting authority if the results could reasonably be expected to contribute to European or international standards.

<u>*Expected outcome*</u>

International regulations addressing CO_2 emissions are forcing all industries to rethink their processes to become more sustainable. When it comes to the heavy-duty transport or shipping industry for instance, the use of liquified hydrogen (also referred to as liquid hydrogen or LH_2) as an energy carrier and/or fuel appears essential in the short- to mid-term to reach the set objectives.

Transfer of LH_2 and its technical handling is relatively well known for industrial gas or space applications. However, experience with LH_2 in public and populated areas in new distribution applications, such as truck refuelling stations or port bunkering stations for example, is limited or non-existent.

Project results are expected to contribute to all the following expected outcomes:

- Detailed risk analysis (hazard identification, frequency and consequence assessment) for LH_2 transferring operations for ships, trucks and stationary tanks fillings;
- Generic hazard (or safety) distances for LH_2 transferring operations in the different applications, also addressing the possible presence of SimOps (Simultaneous Operations), to be implemented in codes and standards and to be suggested as first estimates for permitting;
- Guidelines for design of LH_2 transferring facilities (safety barriers, mitigation devices, layout, fire protection, pad material, venting);
- Consensual loading procedures (hose connection & disconnection, purging, grounding, instrumentation, certification of personnel) for LH_2 transferring operations;
- Disseminate the project outcomes to authorities (giving permits), notified bodies and other industrial actors;

- Provide science-based inputs to appropriate international standardisation activities.

Project results are expected to contribute to all of the following objectives of the Clean Hydrogen JU SRIA: (especially for Cross-cutting issues - Area: Safety, Pre-Normative Research and Regulations, Codes and Standards):

- Increase the level of safety of hydrogen technologies and applications;
- Support the development of RCS for hydrogen technologies and applications, with the focus on standards;
- Contribute to the SRIA KPIs for Safety, PNR & RCS, organising safety workshops (Targets: 2024 = 2 workshops/year, 2030 = 4 workshops/year);
- Contribute to the SRIA KPIs for Safety, PNR & RCS, providing inputs for developing Standards, Technical Specifications, or Technical Reports at the international level (Targets: 2024 = 0.9 No/ project, 2030 = 1 No/ project).

Scope

The risk management aspects concerning the transfers of LH_2 are critical and need to be technically addressed to provide a solid basis for future standardisation and safety regulation. The project should provide practical outputs (as safe procedures and installation/implantation rules) based on the current LH_2 hazards knowledge available and/or developed in previous projects, such us the FCH 2 JU PRESLHY and HyResponder projects[97] for instance.

Proposals should:

- Define at least, but not limited to, 3 applications related to hydrogen mobility involving LH_2 transfer such as filling a stationary tank, bunkering of ships or refuelling a truck;
- Define the LH_2 transfer devices (hoses, vents) and operational conditions (mass flow rate, temperature, pressure);
- Perform a risk analysis of the operations for each application including the definition of the accidental scenarios, their quantification in frequencies and consequences;
- Propose safety barriers, suitable hazard zoning strategies and separation distances and validate their efficiency;
- Analyse the possible hazards and risks of co-activities and simultaneous operations and determine, if needed, additional validated barriers and separation distances;
- Disseminate risk-based recommendations and guidelines on LH_2 transferring facilities;
- Develop and disseminate consensual loading procedures (hose connection & disconnection, purging, grounding, instrumentation, certification of personnel) for LH_2 transferring operations;
- Provide science-based recommendations, guidelines and procedures to the concerned industry groups and standardization committees.

Proposals should identify and target the relevant standard(s) at the scope and activities should envisage links and synergies with existing platforms and/or projects on LH_2 as well as means of collaboration with similar activities ongoing internationally. Proposals are

[97] https://www.clean-hydrogen.europa.eu/projects-repository_en

encouraged to include a formal standardisation body within the consortium.

Proposals are expected to contribute towards the activities of Mission Innovation 2.0 - Clean Hydrogen Mission. Cooperation with entities from Clean Hydrogen Mission member countries, which are neither EU Member States nor Horizon Europe Associated countries, is encouraged (see section 2.2.6.8 International Cooperation).

TC5-04: Safe hydrogen injection management at network-wide level: towards European gas sector transition

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of around EUR 3.00 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 3.00 million
Type of Action	Research and Innovation Action
Technology Readiness Level	Activities are expected to start at TRL 3 and achieve TRL 6 by the end of the project[98] See General Annex B.
Legal and financial set-up of the Grant Agreements	The rules are described in General Annex G. The following exceptions apply: Beneficiaries must, up to 4 years after the end of the action, inform the granting authority if the results could reasonably be expected to contribute to European or international standards.

Expected outcome

To date, the approach taken to inject hydrogen in the gas networks is left to be defined on a local basis in terms of concentration threshold, locations and purity. This fragmentation could cause significant interoperability issues, particularly when the quantities of hydrogen injected into the gas network will be more widespread geographically and probably variable in time. The impact on gas transportation and distribution (T&D) network components (e.g. valves, fittings, reduction stations, etc) and on all end-users connected to the gas infrastructure, with respect to the nominal 100% hydrogen and transients in the blend compositions is not fully understood.

To address these gaps, it is vital to map European gas T&D infrastructure and interact with operators in order to collect information about materials, components, technology and their readiness for hydrogen blending. It is also vital to develop knowledge for localisation of hydrogen injection, managing concentration fluctuations for blends and a detailed understanding of the implications of repurposing pipes for hydrogen duty.

The need for protocols for inspection and monitoring emerges from the development of networks carrying new gases or gases for which they were not originally designed. Preventive measures (inspection) and solutions to mitigate the impact of hydrogen at component level are still at a low level of maturity or not yet fully adapted to the integration of hydrogen into networks.

Project results are expected to contribute to the following expected outcomes:

[98] TRLs at the start and at the end of the project are not referred to the specific actions proposed in the scope, but to the whole set of actions proposed, that due to the wide scope and the interaction with the harmonization and regulatory activities will vary from TRL 3 to TRL 6.

- Definition of methods, tools and technologies for multi-gas network management and quality tracking, including simulation, prediction and safe management of transients, in view of widespread hydrogen injection in a context of European-wide interoperability and gas market reform;
- Best practice guidelines for handling the safety of hydrogen in the natural gas infrastructure, managing the risks (with prevention and mitigation protocols) for guaranteeing the safe interoperability of gas transport at European level;
- Mapping and assessing T&D infrastructure components at European level to identify best available technologies, the hydrogen readiness of components, network technologies and monitoring protocols in order to steer stakeholders towards effective regulation and technical standards, network repurposing and modernisation investments.

Project results are expected to contribute to all of the following objectives of the Clean Hydrogen JU SRIA (especially for Pillar 2, Hydrogen Storage and Distribution –Sub Pillar: Hydrogen in the Natural Gas Grid, and for Cross-cutting issues - Area: Safety, Pre-Normative Research and Regulations, Codes and Standards):

- Development of technologies and materials to facilitate the transportation of hydrogen via the natural gas grid;
- Enable through research and demonstration activities the transportation of hydrogen through the natural gas grid either by blending or via repurposing to 100% hydrogen;
- Increase the level of safety of hydrogen technologies and applications;
- Support the development of RCS for hydrogen technologies and applications, with the focus on standards;
- Contribute to the SRIA KPIs for Safety, PNR & RCS, organising safety workshops (Targets: 2024 = 2 workshops/year, 2030 = 4 workshops/ year);
- Contribute to the SRIA KPIs for Safety, PNR & RCS, providing inputs for developing Standards, Technical Specifications, or Technical Reports at the international level (Targets: 2024 = 0.9 No/ project, 2030 = 1 No/ project).

Scope

This topic aims to define comprehensive technical information, standard protocols for the managing of a multi-gas network and give scientific-based evidence in order to help stakeholders towards the development of effective regulation and technical standards, network repurposing and modernisation investments.

The GERG CEN H2 PNR project[99] has helped to define a comprehensive list of impacted standards and a gap analysis for managing these standards through targeted PNR, and the project should aim to interact with these identified priorities at CEN TC level where possible.

Proposals should also support the aims of the Hydrogen and Decarbonized Gas Market Package[100] which provides the regulatory framework within which future gas networks will operate.

Proposals should address the management and control of transients of composition of

[99] https://www.gerg.eu/project/hydrogen/
[100] https://ec.europa.eu/energy/topics/markets-and-consumers/market-legislation/hydrogen-and-decarbonised-gas-market-package_en

natural gas and hydrogen mixtures for safe end use. In particular:

- Injection of hydrogen in existing gas grids can lead to a heterogeneous quality delivered to end-users. Quality variation should be predicted and controlled and injection strategies of hydrogen in the gas grid are needed.

  Facing multiple production and injection points, complex grids, time-varying injection volumes and end-user demand volumes, the goal to predict and control gas quality in hydrogen blends could be addressed with a twofold approach. On one hand, by developing open modelling tools for gas network simulation, on the other hand, by identifying key technologies for quality tracking and the mitigation of quality variation in the natural gas network.

  Solutions for the coordination of the hydrogen production and blending installations and their operations are required both from technical and regulatory points of view to guarantee quality control and to provide gas operators with the tools to manage a harmonised playing field for investors at EU level. Therefore, modelling should identify strategies for optimal injection points and gas network control, to evaluate pure or blended hydrogen injection strategies and to perform gas quality tracking and control. The project should analyse these issues in view of the intersectoral integration through power-to-hydrogen. Both gas distribution and transmission networks should be considered.

  On the other hand, it is necessary to identify key technologies for quality tracking and the ones that are able to subsequently mitigate quality variation in the natural gas network, fully integrated with a dedicated ICT infrastructure for the digitalisation of the sector. Guidelines can also provide input for new technical norms that may spur innovation in selected network technologies for quality tracking and control.

  Proposals should provide guidance to assist the injection of hydrogen in the gas infrastructure across Europe, consistently highlighting the new issues, the technical and administrative barriers and gaps by using a clear methodology that will give the basis to the definition of EU technical standards, which should include also the ICT protocols.

In addition, proposals are strongly encouraged to address the following activities:

- Analysis of delivered gas quality impacts on repurposed and new pipelines.

  Proposals are expected to build on previous projects investigating the effects of hydrogen quality through repurposed pipelines (such as the Cadent Gas Hydrogen Grid to Vehicle project[101]), with a specific focus on the effect of the hydrogen presence (and its variation) on all the items of the networks (e.g. valves, fittings, sealants, reduction stations, etc).

  In addition, proposals are encouraged to perform gas quality testing of real samples. The analysis obtained will be undertaken along the delivery chain from the industrially produced hydrogen to storage and transmission and distribution through to final appliances. On the one hand, the work will support European industry to confidently produce, transport and store hydrogen with no impact to the end-user due to gas quality issues. On the other hand, it will help in generating a methodology to set specific hydrogen acceptability and hydrogen variation limits in sections of the gas infrastructure, depending on the status of the existing infrastructure and the

[101] https://smarter.energynetworks.org/projects/nia_cad0022

functional requirement of the connected appliances.

The results will support the further development and revision of a new EN standard for hydrogen quality in gas grids. It will also provide knowledge to develop new guidance on performing risk assessments for hydrogen-natural gas blends quality in gas grids.

- Analysis and inspection of infrastructure component behaviour in the presence of hydrogen.

  Proposals are expected to build on the outputs of CEN H2 PNR (GERG) and other projects such as the HIGGS project[102]. Additionally, it is expected to cooperate with the project resulting from topic HORIZON-JTI-CLEANH2-2022 -02-01 which will be developing parallel testing protocols for metallic materials. A systemic analysis of the existing grid infrastructure is expected, shifting from single material compatibility to the evaluation of the fitness-for-purpose of components of the gas infrastructure.

  Proposals are encouraged to develop a database of gas grid components (valves, fittings, gaskets, sealant, metering, odorisation, reduction stations, etc) behaviour in the presence of hydrogen correlated to the operating conditions of the networks and the materials that constitute them, assessing the compatibility of vintage and new gas infrastructures with hydrogen. The expected outcomes are therefore the mapping of components installed in European gas networks and the assessment of the compatibility of each single item. A ready-for-hydrogen ranking of all the existing items on the gas networks, together with the knowledge of the acceptability limits of end-user appliances, may be useful to define the best available network configurations for hydrogen blending management, different blending limits, priorities for modernisation and repurposing of existing assets, different safety requirements and protocols for the inspection (e.g. leak detection) and consequent management of risks. This should also be mapped with the quality and mitigation requirements for existing appliances (e.g. taken from the outcomes of projects such as THyGA[103]).

  Based on the outcomes of the above activities proposals are expected to develop protocols for inspecting (in-line inspection and non-destructive testing tools) and monitoring the integrity of pipelines and other equipment exposed to hydrogen, for the detection of the leakages and the correlated countermeasures and offer innovative solutions for non-inspectable pipes, both at transmission and distribution level.

Proposals should identify and target the relevant standard(s) at the scope and activities should envisage links and synergies with existing platforms and/or projects as well as means of collaboration with similar activities ongoing internationally. Proposals are encouraged to include a formal standardisation body within the consortium.

Proposals are expected to contribute towards the activities of Mission Innovation 2.0 - Clean Hydrogen Mission. Cooperation with entities from Clean Hydrogen Mission member countries, which are neither EU Member States nor Horizon Europe Associated countries, is encouraged (see section 2.2.6.8 International Cooperation).

[102] https://www.clean-hydrogen.europa.eu/projects-repository_en
[103] https://www.clean-hydrogen.europa.eu/projects-repository_en

TC5-06: Development of validated test methods and requirements for measuring devices intended for measuring NG/H2 mixtures

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of around EUR 2.00 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 2.00 million
Type of Action	Research and Innovation Action
Technology Readiness Level	Activities are expected to achieve TRL 4 by the end of the project.[104] See General Annex B.
Legal and financial set-up of the Grant Agreements	The rules are described in General Annex G. The following exceptions apply: Beneficiaries must, up to 4 years after the end of the action, inform the granting authority if the results could reasonably be expected to contribute to European or international standards.

<u>*Expected outcome*</u>

No validated test methods for measuring devices used in the distribution and transmission of hydrogen-enriched natural gas currently exist. Therefore, a scientific approach to identify the hydrogen limits in NG mixtures and tolerances for the currently implemented measuring devices in the existing networks such as, for example, but not limited to, gas meters, volume conversion devices, pressure transmitters and transducers, quality analysers, is not possible. To date, type approval for measuring devices is carried out based on dedicated EN standards while the test gases composition is commonly in accordance with EN 437:2018, Test gases - Test pressures - Appliance categories (which limits the percentage of hydrogen in the test gases to 23%) or EN ISO 6145 method for quality analyser. However, there is no confirmation that the requirements and the procedure of the existing standards allow a validated assessment of the performances of measuring devices in the case of different and unsteady hydrogen and NG mixtures (considering hydrogen concentration in the range between 0% to 100% vol.), and especially for pure hydrogen. Since larger quantities of hydrogen are expected to be injected into the European gas networks in the future, the existing situation represents a barrier to the decarbonisation of the existing NG networks.

Results of the work will facilitate the development of revisions and updates of the European standards concerning measuring devices which are installed on the gas transport and distribution infrastructure, subject to the requirements of the MID 2014/32/EU, OIML (OIML R137, OIML R140, etc.) and other relevant metrological rules.

Project results are expected to contribute to all the following expected outcomes:

- Identifying hydrogen content limits for currently installed measuring devices (e.g. gas meters, volume conversion devices, pressure transmitters and transducers, quality

[104] TRL of 4 is to be meant as readiness level of the test methods and requirements rather than technology.

analysers) on the gas networks in terms of technical and metrological performances at different levels of hydrogen rate under dynamic network conditions;

- Supporting the manufacturing industry of gas measuring devices to have a clear vision of the problems connected to the presence of hydrogen blending with natural gas, helping them define their industrial plans concerning, for example, but not limited to, innovations aiming to ensure accurate measurement and billing;
- Supporting the natural gas TSOs (Transmission System Operators) and DSOs (Distribution System Operators) in the identification of the efforts required to convert existing natural gas networks to allow the safe transportation and distribution of different amounts of hydrogen and to ensure the most accurate billing to the final end-users;
- A boost in the entry into the market of hydrogen production technologies, thanks to the identification of potential barriers and technical solutions about the performances of measuring devices in order to accommodate variable volumes of hydrogen in the gas grid.

Project results are expected to contribute to all of the following objectives of the Clean Hydrogen JU SRIA (especially for Pillar 2, Hydrogen Storage and Distribution –Sub Pillar: Hydrogen in the Natural Gas Grid, and for Cross-cutting issues - Area: Safety, Pre-Normative Research and Regulations, Codes and Standards):

- Development of technologies and materials to explore and support the transportation of hydrogen via the natural gas grid;
- Enable through research and demonstration activities the transportation of hydrogen through the natural gas grid either by blending or via repurposing to 100% hydrogen;
- Support the development of RCS for hydrogen technologies and applications, with the focus on standards.
- Contribute to the SRIA KPIs for Safety, PNR & RCS, providing inputs for developing Standards, Technical Specifications, or Technical Reports at the international level (Targets: 2024 = 0.9 No/ project, 2030 = 1 No/ project).

<u>*Scope*</u>

Building on existing results from previous and ongoing projects such as, for example, NewGasMet[105] or Decarb[106], or the technical documents by EURAMET, experimental data from lab tests is necessary to validate technical and metrological requirements for measuring devices.

Proposals should develop validated test methods and requirements on existing measuring devices used in the gas distribution and transmission networks, that will result, among others, in the definition of hydrogen limits and tolerances for currently used measuring devices. The measuring devices to be considered should include, at least, but not limited to gas meters, volume conversion devices, pressure transmitters and transducers, and quality analysers.

105 https://newgasmet.eu/

106 https://www.euramet.org/research-innovation/search-research-projects/details/project/metrology-for-decarbonising-the-gas-grid/?tx_eurametctcp_project%5Baction%5D=show&tx_eurametctcp_project%5Bcontroller%5D=Project&L=0&cHash=68727f268894f4b2afd6c2cd62e69051

Proposals should:

- Define the test condition range for the measuring devices that will be tested: temperature, pressure, total gas mixture flowrate, etc. based on the expected in-field conditions (transportation and/or distribution networks). Hydrogen percentages should cover the range between 0% to 100% vol;
- Select the characteristics of the tested measuring devices. Particularly, the project should define specific criteria for the selection of:
  - Flow measuring devices that will be tested such as the type of gas meters and related size (maximum flowrate);
  - Quality analysers, including but not limiting to gas chromatographs;
  - Pressure transmitters and transducers;
  - Any other measuring devices included in the project.

  The requirements for accuracy and metrological traceability of reference measuring equipment should be identified to test the measuring devices addressed in the project;
- Define a coherent methodology and proper tests programs (i.e. protocols) with the aim of identifying hydrogen limits and tolerances for the measuring devices indicated in the project. Particularly, the tests should consider different hydrogen percentages in the Natural Gas mixture in both stationary (fixed hydrogen concentration) and dynamics (variable in time hydrogen concentration) conditions;
- Perform testing activities based on the protocols designed. Testing of measuring devices should be performed in at least two laboratories and/or test centres to ensure the requirements of the developed procedures;
- Evaluate the impacts on the measuring devices in order to provide indication for further technical requirement, for example, but not limited to, the evaluation of the impact of hydrogen on the current recognised algorithms used for calculation of compressibility factor Z (EN ISO 12213, part 1 to 3) and their suitability for metrological purposes;
- Provide recommendations and dissemination for updating and/or development of new standards at international level. Recommendations should be provided on the following points, at least to European and National gases and metrology associations:
  - Development and validation of technical and metrological requirements:

    In consideration of test results from the previous activities, development, validation and conformity assessment of technical and metrological requirements for measuring devices is needed to assure compliance of the currently used systems according to the requirements defined by standards or law for safety and process control in hydrogen technologies (as MID, OIML and other applicable metrological rules).
  - Definition of limits and tolerances for measuring devices:

    Experimental definition of hydrogen limits and tolerances for currently used measuring devices both in terms of components' failure and degradation (i.e. safety) and metrological performances.

The project should identify and target the relevant standard(s) at the scope and activities should envisage links and synergies with current research projects concerning the measure of NG/H_2 mixtures, such as those of the European Metrology Programme for Innovation and Research (EMPIR[107]) and European Partnership on Metrology of EURAMET. Collaboration with the activities of the Selected Research Topics SRT-v09 "Metrology for the hydrogen supply chain (Met4H2)" [108], which is expected to start in 2022, should also be foreseen. Proposals are encouraged to include a formal standardisation body within the consortium.

Proposals are expected to contribute towards the activities of Mission Innovation 2.0 - Clean Hydrogen Mission. Cooperation with entities from Clean Hydrogen Mission member countries, which are neither EU Member States nor Horizon Europe Associated countries, is encouraged (see section 2.2.6.8 International Cooperation).

[107] https://www.euramet.org/research-innovation/research-empir/about-empir/

[108] https://msu.euramet.org/current_calls/greendeal_2021/index.html

EC-01: Research & Innovation co-operation with Africa on hydrogen

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of EUR 1.00 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 1.00 million.
Type of Action	Coordination and Support Action
Technology Readiness Level	n/a
Eligibility	The conditions are described in General Annex B. The following additional eligibility criteria apply: At least three partners from three different African countries must be part of the consortium. Due to the scope of this topic, legal entities established in all member states of the African Union are exceptionally eligible for EU funding.

Expected outcome

Project results are expected to contribute to all of the following expected outcomes:

- Reinforce the activities in the long term of the African Union and European Research and Innovation Partnership on Climate Change and Sustainable Energy;
- Provide knowledge and multidisciplinary scientific based evidence of renewable hydrogen including the environmental, social and economic trade-offs;
- Benefit African and European researchers, industry, investors, financial institutions, and decision makers;
- Provide policy recommendations as to how, where and when Renewable Hydrogen deployment in Africa can best contribute to the continent´s clean energy transition while fostering sustainable growth and development in line with EU policies, values and interests;
- A sustained network of African experts and expertise in renewable hydrogen and its application;
- Contribute to increasing renewable energy generation in the African energy systems.

Scope

The aim of this research is to gain a better understanding and identify the necessary measures to be taken, to create enabling conditions for the development of renewable hydrogen technology and market that would contribute to the social, economic and environmental transition of the African continent.

The results of this comprehensive and multidisciplinary research would benefit African and European researchers, investors, industry, financial institutions, as well as policy makers. For the European Union, this research will contribute to shape future cooperation with

African partner countries envisaging the development of renewable hydrogen value chains, aligned with international best standards and positioning the European industry as a credible investment partner.

The proposal should not focus on specific renewable hydrogen technology. The proposal should explore potential research, innovation and technological options for production, storage, transportation, distribution and usage of renewable hydrogen and the associated environmental impacts (considering a life cycle perspective); exploring alternative business models, techno-economic aspects, industrial implications and market opportunities; geopolitical consideration vis a vis the development of a global hydrogen market and the socio-economic implications on the African continent; network requirements, etc.

Proposals should identify the potential geographical and thematic areas where EU and African countries could develop mutual understanding and cooperation based on local production of hydrogen based on renewable energy locally available. At least two such areas should be developed in detail to exemplify the benefits and impacts.

One of the main deliverables would be a strategic and comprehensive innovation roadmap (SRI) to technology development and market introduction in the context of African national and continental industrial strategy and energy infrastructures. This SRI needs to highlights the mutual benefits to stakeholders, citizens and policies of both African Union and European Union.

In addition, it should:

- take into consideration the associated social, economic and environmental implications of alternative deployment paths of renewable hydrogen and other power fuels in Africa taking into consideration a life cycle approach and the relevant global value chains;
- identify possible barriers and opportunities to the introduction of renewable hydrogen technologies.

The proposal should also:

- define the life cycle assessment (LCA) methodology to assess the social, economic and environmental impacts of such development
- foresee the inventory of relevant regulations and standards, and absence thereof, as well as policy and other incentives planed or in place to deliver renewable hydrogen projects.
- identify local training needs

The proposal should take into account any relevant past and current studies on renewable hydrogen in Africa. Building on these studies the proposal should use the existing activities to propose the creation of a network of the major African actors in the area of hydrogen produced from renewable energy either directly or indirectly, transport of hydrogen and use of hydrogen. Proposals should ensure that the network created is sustainable and long lasting.

HYDROGEN VALLEYS

FCH JU-02-A: Hydrogen Valleys (large-scale)

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of around EUR 25.00 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 25.00 million
Type of Action	Innovation Action
Technology Readiness Level	The TRL of the applications in the project should be at least 6 at the beginning of the project while the overall concept should target a TRL 8 at the end of the project. See General Annex B.
Admissibility conditions	The conditions are described in General Annex A. The following exceptions apply: The page limit of the application is 70 pages.
Eligibility	The conditions are described in General Annex B. The following additional eligibility criteria apply: At least one partner in the consortium must be a member of either Hydrogen Europe or Hydrogen Europe Research. The maximum Clean Hydrogen JU contribution that may be requested is EUR 25.00 million – proposals requesting Clean Hydrogen JU contributions above this amount will not be evaluated.
Procedure	The procedure is described in General Annex F. Seals of Excellence will be awarded to applications exceeding all of the evaluation thresholds set out in this work programme, but cannot be funded due to lack of budget available to the call.
Legal and financial set-up of the Grant Agreements	The rules are described in General Annex G. The following exceptions apply: Purchases of equipment, infrastructure or other assets used for the action must be declared as depreciation costs. However, for the following equipment, infrastructure or other assets purchased specifically for the action (or developed as part of the action tasks): hydrogen production plany, distribution and storage infrastructure and hydrogen end-uses, costs may exceptionally be declared as full capitalised costs.

Expected outcome

Building on the successful experience of previous years (Hydrogen Valleys in the FCH 2 JU call 2019 and Hydrogen Islands in the FCH 2 JU call 2020), this topics calls for the deployment of a flagship[109] Hydrogen Valley with interlinkages to other places of hydrogen production and/or consumptions outside its boundaries. This represents a novelty as the Hydrogen Valleys supported to date are confined to a specific geography.

Project results are expected to contribute to all of the following expected outcomes:

- Activate a long-lasting hydrogen economy in the targeted region/s and that goes beyond the boundaries of the Hydrogen Valley/s developed as a result of the proposal;
- Replicable model for mutualisation of hydrogen production or distribution and storage, in view of optimisation of investments as key parameter for financial viability;
- At least 5 additional Hydrogen Valleys of at least a similar size and scope as the one required in this topic are initiated in other locations in Europe;
- Improved public perception of hydrogen ecosystems, contributing towards an EU hydrogen infrastructure backbone in any possible way, e.g. HRS network, hydrogen pipeline, NG pipeline retrofitted to hydrogen, etc.

Project results are expected to contribute to all of the following objectives of the Clean Hydrogen JU SRIA for Hydrogen Valleys. In particular:

- System integration: integrating several elements together to improve overall synergies and facilitate sector coupling;
- System efficiency: improvement of overall energy and economic efficiency of the integrated system;
- Improved security and resilience of the energy system, e.g. via hydrogen production using locally available renewable energy sources;
- Market creation: demonstration of new market for hydrogen
- Complementarity of hydrogen with RES, integration with other technologies, existing infrastructure;
- Assessment of the availability and affordability of clean (pollution free) energy provision for industry and cities uses;
- Mutualisation of production or distribution and storage, assuming decentralisation as key parameter;
- Help set or test regulation requirements at the relevant governance level;
- Increase the knowledge management with assessment of the socio-economic and environmental impacts, including the concept of digital twin assuring an effective monitor and optimization strategy for the operation and further development of the valley;
- Development of public awareness of hydrogen technologies including

[109] For definition of flagship see section 5.3. of the Clean Hydrogen JU Strategic Research and Innovation Agenda 2021 – 2027

contributions from Social Science and Humanities if this was relevant.

In addition, proposals should demonstrate how they intend to reach the KPIs of the Clean Hydrogen JU SRIA 2021-2027 for each of the technologies deployed in the Hydrogen Valley.

Scope

A Hydrogen Valley is a defined geographical area where hydrogen serves more than one end sector or application in mobility, industry and energy. They typically comprise a multi-million euro investment and cover all necessary steps in the hydrogen value chain, from production (and often even dedicated renewable electricity production) to subsequent storage and its transport & distribution to various off-takers. Whilst most of the projects are located in Europe, over the past years, Hydrogen Valleys have gone global, with new projects emerging worldwide.

Hydrogen Valleys are starting to form first regional "hydrogen economies”. Already under the FCH JU provided support to a number of Hydrogen Valleys[110] across different locations in Europe and of different sizes. It is however still necessary to accelerate the deployment of additional Hydrogen Valleys already now in view of the objectives of the European hydrogen strategy[111]. To do this it is necessary to have testbed projects to act as first real-life cases for piloting global hydrogen markets. These projects needs to be expanded in scale to demonstrate the full range of benefits from the use of hydrogen as an energy carrier. This topic addresses this need by calling for a Hydrogen Valley of a large scale with high levels of hydrogen production. It also intends to stimulate the activation of hydrogen markets that go beyond the boundaries the Hydrogen Valley location.

The scope of this topic is to develop, deploy and demonstrate a large-scale hydrogen valley with interlinkages to other places of hydrogen production and/or consumptions outside its boundaries. The size and other characteristics are given further below. To increase the impact, it is encouraged to accommodate these requirements across two separate interconnected valleys located in different intra-EU regions[112] whether within the same Member State/Associated country or not; in such cases, exchange of hydrogen is expected to exceed 20% of the overall annual production in order to have a meaningful impact, and individual regions would not be required to achieve the minimum project size of 5,000 tonnes/yr (outlined below) but would still be required to demonstrate minimum thresholds for percentages dedicated to end uses in various sectors as outlined below.

Technical

Proposals should:

- Showcase the ability of hydrogen and its associated technologies to decarbonise different sectors in EU through this renewable hydrogen flagship project;
- Demonstrate how hydrogen enables sector coupling and allows large integration of renewable energy on the selected territory;
- Include clear plans for transport, storage and distribution of hydrogen;
- Cover the complete value chain of hydrogen from production to distribution, storage and end-use in order to decarbonise regions by harnessing renewables with

[110] https://www.clean-hydrogen.europa.eu/projects-repository_en
[111] https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf
[112] For definition purposes, regions are those defined as such by the European Commission: https://ec.europa.eu/eurostat/web/regions-and-cities/overview

significant fluctuations in seasonal energy demand, while at the same time allowing matching supply and demand on a daily basis. The proposed solution should thus provide energy flexibility and improve the Regions' system resilience through the use of renewable hydrogen;

- Foresee enough time for monitoring and assessment and at least 2 years of operations. The monitoring strategy should as a minimum allow to assess compliance with the KPIs of the Clean Hydrogen JU SRIA 2021-2027 for each of the technologies covered, as mentioned in the expected outcome section.

Size and characteristics of the Hydrogen Valley

Proposals should demonstrate:

- Production of at least 5,000 tonnes of renewable hydrogen[113] per year using new hydrogen production capacity. Due to the large volumes of hydrogen involved, production plants may be distributed across the territories involved.
- At least two FCH applications from at least two different sectors should be part of the project. The following sectors and applications can be considered for the use of renewable hydrogen, with a clear focus on energy, industry and transport sectors:
    - Industry sector: Industrial application valorising hydrogen, like refineries, steel industry, metallurgy, glass industry, ammonia or methanol production. Other industry applications are not excluded;
    - Energy sector: Possible applications on heat and power for commercial/residential buildings, service sector and industry, hydrogen gen-sets, backup-power systems, and electric supply of critical infrastructure. Gas grid injection, in blending mixtures and its impact assessment in order to promote the progressive decarbonisation of the gas grid should also fall under this sector;
    - Transport sector: Buses, cars (private cars and / or captive fleets such as taxis), delivery vans and small trucks, medium and heavy-duty trucks (also for long haul trips), specialty vehicles (like garbage trucks and sweepers), trains, waterborne applications (like boats/ships and port logistics), airborne applications (small and medium airplanes, drones and UAVs), material handling vehicles. Other transport applications are not excluded.

It is expected that the majority of the produced hydrogen will be dedicated to industrial applications, yet at least 20% of the hydrogen produced should serve other applications. In addition, if applicable as indicated above, cross-regional exchange/distribution of hydrogen is expected to be at least 20% of the hydrogen produced in the project and could be bidirectional depending on the location of storage.

The volumes of hydrogen produced and distributed for the different end uses should be consistent with the amount of investment considered.

Hydrogen Markets

Proposals should:

[113] As defined in the EU Taxonomy – see: https://eur-lex.europa.eu/resource.html?uri=cellar:d84ec73c-c773-11eb-a925-01aa75ed71a1.0021.02/DOC_2&format=PDF, p.57

- Demonstrate existing and new markets for renewable hydrogen, especially when applications are used in synergies;
- If applicable, pilot implementation of a transnational-regional/intra-EU renewable (certified via a relevant scheme) hydrogen market / trading of hydrogen across regions/borders.

Economic growth

Proposals should:

- Demonstrate how all actors, public and private, at European national and regional level will work together, across the entire value chain, to build a dynamic hydrogen ecosystem in the Member States/Regions involved. In particular proposals should demonstrate how the Hydrogen Valley development will be accompanied by economic growth, skills development and job creation;
- Promote and enable a renewable hydrogen ecosystem in the region(s), as a new economic vector and as mechanism of creating value for their population;
- Promote the economic growth and focus shifting of EU regions to new technologies and areas (e.g. reindustrialisation based on hydrogen technologies);
- Demonstrate the expected value added that the development of the Hydrogen Valley will bring to the affected region/s by including the intended approach that would be followed to maximise the value added created.

Impact and replicability

Proposals should:

- Develop a long-term vision on how the Hydrogen Valley developed is expected to grow also in view of its potential role in an Important Project of Common European Interest that may be in the making;
- Demonstrate the replicability and scalability of the project with the aim of facilitating further deployments of Hydrogen Valleys in other locations in Europe. Proposals should therefore address efforts to provide and transfer the learnings on how to best scale-up and transfer the solutions investigated within the selected territory to other interested areas. Proposal are therefore expected to develop a clear replication strategy and to engage with other regions in Europe, e.g. peer-to-peer exchange activities, to foster replication already during the duration of the action, with special attention placed on projects including Central and Eastern European regions where Hydrogen Valleys may be less developed at present. In doing this, proposals should address technical and economic feasibility and also aspects related to Regulation Codes and Standards. In that sense, learnings from previous similar projects (e.g. H2020 projects BIG-HIT[114], HEAVENN[115] and Hysland[116]) should be lifted in view of mutualising and standardising impact and replicability aspects. Proposals should demonstrate how they intend to create links with other Hydrogen Valleys initiatives in Europe (e.g. S3 Hydrogen Valleys Platform[117], HyLand[118] Regions in Germany), but

114 https://www.bighit.eu
115 https://heavenn.org
116 https://greenhysland.eu
117 https://s3platform.jrc.ec.europa.eu/hydrogen-valleys
118 https://www.hy.land/

also international (e.g. Mission Innovation 2.0 - Clean Hydrogen Mission[119]);

- Include sufficiently targeted and professional communication activities and campaigns with the aim to increase public acceptance of hydrogen ecosystems. Given the flagship nature of this topic, the proposals are expected to pay attention to this aspect and to demonstrate how this would be professionally addressed.

Commitment of stakeholders and additional sources of financing/funding

Proposals should contain a calendar clearly defining the key phases of the implementation of the action (i.e. preparation of the specifications of equipment, manufacturing, deployment and operation) and their duration. Proposals should foresee enough time for monitoring and assessment.

Applicants may consider additional synergies with other Programmes (e.g. European Structural and Investment Funds, Recovery and Resilience Facility, Just Transition Fund, Connecting Europe Facility, Innovation Fund, Modernisation Fund, LIFE, etc.) and/or clustering with other projects within Horizon Europe or funded under other EU, national or regional programmes, or having loans through the EIB or other promotional or commercial banks; such synergies should be reflected in a financing structure and strategy describing the business model, including envisaged sources of co-funding/co-financing and in line with state-aid rules.

Evidence of the Commitment and role of public authorities (Member States, Regions and Cities) and of any other necessary stakeholders at least in the form of Letters of Intent (LOI) should be provided. The practical implementation of this LOI will be followed during the Grant Agreement implementation.

This topic is expected to contribute to EU competitiveness and industrial leadership by supporting a European value chain for hydrogen and fuel cell systems and components.

It is expected that Guarantees of origin (GOs) will be used to prove the renewable character of the hydrogen that is produced/used. In this respect consortium may seek out the issuance/purchase and subsequent cancellation of GOs from the relevant Member State issuing body and if that is not yet available the consortium may proceed with the issuance/purchase and cancellation of non-governmental certificates (e.g CertifHy[120]).

Proposals should provide a preliminary draft on 'hydrogen safety planning and management' at the project level, which will be further updated during project implementation.

Proposals are expected to contribute towards the activities of Mission Innovation 2.0 - Clean Hydrogen Mission. Cooperation with entities from Clean Hydrogen Mission member countries, which are neither EU Member States nor Horizon Europe Associated countries, is encouraged (see section 2.2.6.8 International Cooperation).

[119] http://mission-innovation.net/missions/hydrogen/
[120] https://www.certifhy.eu/

FCH JU-02-B: Hydrogen Valleys (small-scale)

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of around EUR 8.00 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 8.00 million.
Type of Action	Innovation Action
Technology Readiness Level	The TRL of the applications in the project should be at least 6 at the beginning of the project while the overall concept should target a TRL 8 at the end of the project. See General Annex B.
Admissibility conditions	The conditions are described in General Annex A. The following exceptions apply: The page limit of the application is 70 pages.
Eligibility	The conditions are described in General Annex B. The following additional eligibility criteria apply: At least one partner in the consortium must be a member of either Hydrogen Europe or Hydrogen Europe Research. The maximum Clean Hydrogen JU contribution that may be requested is EUR 8.00 million – proposals requesting Clean Hydrogen JU contributions above this amount will not be evaluated.
Procedure	The procedure is described in General Annex F. Seals of Excellence will be awarded to applications exceeding all of the evaluation thresholds set out in this work programme but cannot be funded due to lack of budget available to the call.
Legal and financial set-up of the Grant Agreements	The rules are described in General Annex G. The following exceptions apply: Purchases of equipment, infrastructure or other assets used for the action must be declared as depreciation costs. However, for the following equipment, infrastructure or other assets purchased specifically for the action (or developed as part of the action tasks): hydrogen production plant, distribution and storage infrastructure and hydrogen end-uses, costs may exceptionally be declared as full capitalised costs.

Expected outcome

Building on the successful experience of previous years (Hydrogen Valleys in the FCH 2 JU call 2019 and Hydrogen Islands in the FCH 2 JU call 2020), this topic calls for the deployment of a flagship[121] Hydrogen Valley in areas of Europe with no or limited presence of Hydrogen Valleys such as in Central and Eastern European Countries.

Proposals under this topic are expected to demonstrate how they contribute to the objectives of the European Hydrogen Strategy and the European Green Deal.

Project results are expected to contribute to all of the following expected outcomes:

- At least [5] additional H2 Valleys projects are initiated before 2027;
- Replicable model for production or distribution and storage and end-use applications, in view of optimisation of investments as key parameter for financial viability;
- Improved public perception of H2 ecosystems, with the aim to contributing towards an EU hydrogen infrastructure backbone, e.g. HRS network, H2 pipeline, NG pipeline retrofitted to H2, etc.

Project results are expected to contribute to all of the following objectives of the Clean Hydrogen JU SRIA for H2 Valleys. In particular:

- System integration: integrating several elements together to improve overall synergies and facilitate sector coupling;
- System efficiency: improvement of overall energy and economic efficiency of the integrated system;
- Improved security and resilience of the energy system, e.g. via hydrogen production using locally available renewable energy sources;
- Market creation: demonstration of new market for hydrogen
- Complementarity of hydrogen with RES , integration with other technologies, existing infrastructure,
- Assessment of the availability and affordability of clean (pollution free) energy provision for industry and cities uses;
- Mutualisation of production or distribution and storage, assuming decentralisation as key parameter;
- Help set or test regulation requirements at the relevant governance level;
- Increase the knowledge management with assessment of the socio-economic and environmental impacts, including the concept of digital twin assuring an effective monitor and optimization strategy for the operation and further development of the valley;
- Development of public awareness of hydrogen technologies including contributions from Social Science and Humanities if this was relevant.

In addition, proposals should demonstrate how they intend to reach the KPIs of the Clean Hydrogen JU SRIA 2021-2027 for each of the technologies deployed in the H2 Valley.

[121] For definition of flagship see section 5.3. of the Clean Hydrogen JU Strategic Research and Innovation Agenda 2021 – 2027

Scope

A Hydrogen Valley is covering a defined geographical area in which hydrogen serves in general more than one end user or application in mobility, industry and energy. They typically comprise a substantial financial investment and cover as much as possible the necessary steps in the hydrogen value chain, from production (and often even dedicated renewable electricity production) to subsequent storage and its transport & distribution to various off-takers. Hydrogen Valleys are starting to form regional "hydrogen economies". Such projects are necessary for piloting global hydrogen markets and should be expanded in number or scale to demonstrate the full range of benefits from the use of hydrogen as an energy carrier

The scope of this topic is to develop, deploy and demonstrate a hydrogen valley having the aim to increase in size and characteristics overtime. Particular attention is given to actions supporting the design and development of a Hydrogen Valley in areas of Europe with no or limited presence of Hydrogen Valleys such as in Central and Eastern European Countries.

Technical

Proposals should:

- Showcase the ability of hydrogen and its associated technologies to decarbonise one or two sectors in EU through this renewable hydrogen flagship project;
- Demonstrate how hydrogen enables sector coupling and allows integration of renewable energy on the selected territory;
- Include plans for transport, storage and distribution of hydrogen with a growing level of ambition over the years;
- Cover the complete value chain of H2 from production to distribution, storage and end-use in order to decarbonise a geographical area by harnessing renewables with significant fluctuations in seasonal energy demand, while at the same time allowing matching supply and demand on a daily basis. The proposed solution should thus provide energy flexibility and improve the Regions' system resilience through the use of renewable hydrogen;
- Contain a calendar clearly defining the key phases of the implementation of the action (i.e. preparation of the specifications of equipment, manufacturing, deployment and operation) and their duration. Proposals should foresee enough time for monitoring and assessment. The monitoring strategy should as a minimum allow to assess compliance with the KPIs of the Clean Hydrogen JU SRIA 2021-2027 for each of the technologies covered, as mentioned in the expected outcome section.

Size and characteristics of the H2 Valley demonstration

Proposals should:

- Produce at least 500 tons of renewable H2[122] per year;
- Use the hydrogen produced to supply more than one end sector or application in the mobility, industry, and energy sector. The two main applications should each use at

[122] As defined in the EU Taxonomy – see: https://eur-lex.europa.eu/resource.html?uri=cellar:d84ec73c-c773-11eb-a925-01aa75ed71a1.0021.02/DOC_2&format=PDF, p.57

least 20% of the whole hydrogen produced.

The volumes of H2 produced and distributed for the different end uses should be consistent with the amount of investment considered.

H2 Markets

Proposals should demonstrate existing and new markets for renewable hydrogen, especially when applications are used in synergies.

Economic growth

Proposals should:

- Demonstrate how different actors, public and private, at European national and regional level will work together, across the entire value chain, to build a dynamic hydrogen ecosystem in the geographical area involved. In particular, proposals should demonstrate how the Hydrogen Valley development will be accompanied by economic growth, skills development and job creation;
- Promote and enable a renewable hydrogen ecosystem in the area, as a new economic vector and as mechanism of creating value for their population;
- Promote the economic growth and focus shifting to new technologies (e.g. reindustrialisation based on hydrogen technologies);
- Demonstrate the expected value added that the development of the Hydrogen Valley will bring to the affected region/s by including the intended approach that would be followed to maximise the value added created.

Impact and replicability

Proposals should:

- Develop a medium-to long-term vision on how the Hydrogen Valley developed is expected to grow;
- Demonstrate the replicability and scalability of the project with the aim of facilitating further deployments of Hydrogen Valleys in other locations in Europe;
- Build on the learnings and create links with previous and ongoing similar projects (e.g. H2020 projects BIG-HIT[123], HEAVENN[124] and GreenHysland[125]);
- Demonstrate how they intend to create links with other H2 Valleys initiatives in Europe (e.g. S3 Hydrogen Valleys Platform[126], HyLand[127] Regions in Germany) but also international (e.g. Mission Innovation 2.0 - Clean Hydrogen Mission[128]);
- Include sufficiently targeted and professional communication activities and campaigns with the aim to increase public acceptance of H2 ecosystems.

Commitment of stakeholders and additional financing/funding

Applicants may consider additional synergies with other Programmes (e.g. European Structural and Investment Funds, Recovery and Resilience Facility, Just Transition Fund,

[123] https://www.bighit.eu/
[124] https://heavenn.org/
[125] https://greenhysland.eu/
[126] https://s3platform.jrc.ec.europa.eu/hydrogen-valleys
[127] https://www.hy.land/
[128] http://mission-innovation.net/missions/hydrogen/

Connecting Europe Facility, Innovation Fund, Modernisation Fund, LIFE, etc.) and/or clustering with other projects within Horizon Europe or funded under other EU, national or regional programmes, or having loans through the EIB or other promotional or commercial banks; such synergies should be reflected in a financing structure and strategy describing the business model, including envisaged sources of co-funding/co-financing and in line with state-aid rules.

Evidence of the Commitment and role of public authorities (Member States, Regions and Cities) and of any other necessary stakeholders at least in the form of Letters of Intent (LOIs) should be provided. The practical implementation of this LOIs will be followed during the Grant Agreement implementation.

This topic is expected to contribute to EU competitiveness and industrial leadership by supporting a European value chain for hydrogen and fuel cell systems and components.

It is expected that Guarantees of origin (GOs) will be used to prove the renewable character of the hydrogen that is produced/used. In this respect consortium may seek out the issuance/purchase and subsequent cancellation of GOs from the relevant Member State issuing body and if that is not yet available the consortium may proceed with the issuance/purchase and cancellation of non-governmental certificates (e.g CertifHy[129]).

Proposals should provide a preliminary draft on 'hydrogen safety planning and management' at the project level, which will be further updated during project implementation.

Proposals are expected to contribute towards the activities of Mission Innovation 2.0 - Clean Hydrogen Mission. Cooperation with entities from Clean Hydrogen Mission member countries, which are neither EU Member States nor Horizon Europe Associated countries, is encouraged (see section 2.2.6.8 International Cooperation).

[129] https://www.certifhy.eu/

STRATEGIC RESEARCH CHALLENGES

SRC: Addressing the sustainability and criticality of electrolyser and fuel cell materials

Specific conditions	
Expected EU contribution per project	The JU estimates that an EU contribution of around EUR 10 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.
Indicative budget	The total indicative budget for the topic is EUR 10.00 million
Type of Action	Research and Innovation Action
Technology Readiness Level	Activities are expected to start at TRL 2 and achieve TRL 4 by the end of the project.
Eligibility	The conditions are described in General Annex B. The following additional eligibility criteria apply: At least one partner in the consortium must be a member of either Hydrogen Europe or Hydrogen Europe Research. The maximum Clean Hydrogen JU contribution that may be requested is EUR 10.00 million – proposals requesting Clean Hydrogen JU contributions above this amount will not be evaluated.

<u>*Expected outcome*</u>

Electrolyser and fuel cell technologies have reached a level of maturity but still depend heavily on critical raw materials (CRM) in their key components, including platinum group metals (PGM). The outcome of this topic, based on the excellence and expertise of European research, is expected to support European industry in their future development of next generation electrolysers and fuel cells comprising sustainable and recycled materials components and avoiding use of materials of high level of criticality. This topic is a Strategic and Research Challenge[130] expected to contribute to achieving the SRIA targets for electrolysers and fuel cells with radically different and sustainable materials technologies and is a pioneering venture internationally to achieve the ambitious goals of these technologies for European industry at lower environmental cost. This topic will also contribute to advancing European efforts in the Mission Innovation 2.0 - Clean Hydrogen Mission.

Critical materials considered in the topic include both the critical raw materials as defined by the European Union's most recent assessment of CRM[131] and materials with sustainability or environmental concerns, such as those deriving from poly/perfluoroalkyls. Such critical raw materials are considered 'strategic dependencies' in the area of hydrogen technologies.[132]

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[130] For definition of Strategic Research Challenges see section 3.9.of the Clean Hydrogen JU Strategic Research and Innovation Agenda 2021 – 2027

[131] COM(2020) 474 - Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0474

[132] https://ec.europa.eu/info/sites/default/files/strategic-dependencies-capacities.pdf

Project results are expected to contribute to all of the following expected outcomes:

- Contribute to a sustainable and durable EU component supply chain by reducing the CRM content, notably of rare earth metals, PGMs and cobalt, in electrolysers and fuel cells, and by developing replacement materials free of CRMs or environmentally unacceptable or non-sustainable components[133];
- Contribute to increasing the yield of ionomer and CRMs recovered from used cells and membrane electrode assemblies and from scraps and wastes by recycling;
- While keeping at least the same performance and durability as SoA in the Clean Hydrogen JU SRIA, contribute to achieving the PGM reduction target levels of the SRIA for AEM, PEM and alkaline electrolysers and PEMFC for 2024 and beyond, and to reducing the amount of non-recoverable rare earth CRM in catalysts and electrolytes by at least 50% of the current (2021) rare earth CRM content in solid oxide and proton conducting ceramic electrolysers and fuel cells;
- Develop at least three innovative solutions for each technology (PEM, AEM, AEL, PCC and SOC) for further prioritisation and development in specific dedicated RIAs of the Clean Hydrogen JU.

Project results are expected to contribute to all of the following objectives of the Clean Hydrogen JU SRIA:

- Low or free PGM catalysts and reducing critical raw materials in electrolysers and fuel cells according to the following KPIs:
  - For PEMEL catalysts: 1.25 mg_{CRM}/W in 2024 and 0.25 mg_{CRM}/W in 2030
  - For AEL catalysts: 0.3 mg_{CRM}/W in 2024 and CRM-free catalysts in 2030
  - For AEMEL catalysts: 0.4 mg_{CRM}/W in 2024 and CRM-free catalysts in 2030
  - For fuel cell catalysts for HDV: < 0.3 g_{PGM}/kW in 2024 and <0.25 g_{PGM}/kW in 2030
- Develop enhanced recovery processes for PGMs/CRMs in hydrogen-based technologies, for instance:
  - 0.07 g/kW_{el} in 2024 and 0.01 g/kW_{el} in 2030 of non-recoverable CRM (i.e. Pt) as catalyst for low-temperature PEMFC in stationary applications
- AEL: reach high current density without noble metals;
- PEMEL: Reduce precious metals content in catalysts and consider recycling, develop PGM-free catalysts, develop new/advanced membranes;

1. Research at material level for PEMFC to reduce or replace PGM loading;
2. Reducing use of critical raw materials in stationary fuel cells;
3. Research to optimise the CRM and ionomer recycling from FC and electrolysers at end-of-life and processes from scraps and wastes:
   - minimum 30% in 2024 and 50% in 2030 of recycled CRM/PGM (other than Pt) at the system level;

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[133] COM(2020) 667 final , EU chemical strategy for sustainability, https://ec.europa.eu/environment/strategy/chemicals-strategy_en

- minimum 95% in 2024 and 99% in 2030 of Pt recycled from FC/electrolysers at end-of-life;
- minimum 70% in 2024 and 80% in 2030 of ionomer recycled from FC/electrolysers at end-of-life.

4. Minimisation of environmental impact/aim for circularity (energy, resources/material, recyclability).

Scope

A robust supply chain based on validated sustainable materials and components will ensure that the competitiveness of European electrolyser and fuel cell industry is not compromised by future legislative or supply constraints. Some of the current fuel cell and electrolyser technologies have developed from historically niche applications where reliability and performance were deemed more important than long-term sustainability, use of critical raw materials or even cost. This has led to the use of CRM in catalysts, electrolytes, coatings and bipolar plates at levels that are not sustainable over the long term, in the absence of robust separation and recycling routes. It has also led to ubiquitous recourse to ionomer membranes based on perfluoro sulfonic acid electrolytes, novel recycling and validated re-use routes of which are essential.

These materials are critically important in providing the requested high levels of performance and durability of state-of-the-art fuel cells and electrolysers. Breakthrough research is required to find alternatives in order to guarantee the development of a secure and clean hydrogen economy in Europe. To date, focus on reducing precious metals loading has been on reduction or replacement of platinum in proton exchange membrane fuel cells. However, these are only two aspects of a much broader requirement to address the sustainability of the critical materials used with a view to their replacement, reduction and/or recycle/re-use.

This topic addresses the sustainability of the fuel cell and electrolyser component supply chain by the development of technical advancements in (i) replacement of the critical (raw) materials currently used in fuel cells and electrolysers (ii) reduction in the amount of CRM used (iii) developing recycling approaches for materials critical for fuel cells and electrolysers, including novel means of dissociating and separating components.

The following items are within the scope of this topic, which comprise both low and high temperature electrolyser and fuel cell technologies:

- Development, characterisation and validation of novel materials free of critical raw materials (according to the European Union's 2020 CRM list), non-sustainable or environmentally unacceptable components, or with reduced content of such critical materials or components in fuel cells and electrolysers to levels consistent with the SRIA targets without compromising their performance and durability;
- Development of innovative materials, coatings, processing routes, electrode architectures and cell designs to reduce platinum group metal and other CRMs loading in electrolysers and fuel cells;
- Development of breakthrough high-efficiency solutions for recycling the critical materials and critical components of fuel cells and electrolysers, including associated separation steps, with focus on recycling of perfluoro sulfonic acid ionomers for reuse, and on recycling of iridium. Industrially mature technologies are already in use for platinum recycling, however, solutions designed to reduce the potential

environmental impact of non-Pt components of a Pt alloy (for instance, non-exclusively, Ni and Co) within the recycle stream are within the topic scope;

- Lifecycle analyses of the most prospective new technology/ies to demonstrate the sustainability of the proposed solutions.

The development of characterisation and test methods and protocols for evaluation of new and recycled materials and of complete cells is considered within the scope of the topic, however alignment should be made with those in use to qualify current state-of-the-art materials (i.e. those using critical raw materials, platinum group metals and perfluoro sulfonic acid membranes and ionomers).

The novel materials or materials from an intended recycling loop should be validated for their performance and durability in single cells using, as far as possible, EU harmonised protocols (including, as relevant, tolerance to impurities) with direct comparison with the performance/durability of cells with current, state-of-the-art materials under the same conditions.

Consortia should gather comprehensive expertise and experience from the European research community to ensure broad impact by addressing several of the items above. Partners should have proven expertise and the requisite means of electrolyser and fuel cells materials development, characterisation and testing. Industrial guidance is considered essential, for instance through an industrial advisory board. Proposals should explain how the results will be exploited, and how key advances from the activities will be communicated to the broader community to ensure rapid uptake of developments by end-users. To facilitate this communication, dissemination should have high priority and most deliverables should be public. The public annual progress report should include, as necessary, recommendations for future activities.

1.1.2.2 *Conditions of the calls and calls management rules*

Call identifier: **HORIZON-JTI-CLEANH2-2022**

Total budget: **EUR 300.5 mill**

Indicative budget(s)[134]

Topic	Type of Action	Budgets (EUR million)	Expected EU contribution per project (EUR million)	Number of projects expected to be funded
Opening[135]: 01 March 2022 Deadline[136]: 31 May 2022				
TC1-01-A	RIA	2.5	2.5	1
TC1-01-B	RIA	2.5	2.5	1
TC1-02	RIA	5	2.5	2
TC1-05	RIA	4	4	1
TC1-06	IA	9	9	1
TC1-08	RIA	6	3	2
TC2-03	RIA	2.5	2.5	1
TC2-04	RIA	5	5	1
TC2-08	RIA	2.5	2.5	1
TC2-10	IA	5	5	1
TC2-12	RIA	4	4	1
TC2-13	RIA	8	4	2
TC3-02	RIA	6	3	2
TC3-05	IA	30	30	1
TC3-06	RIA	5	2.5	2
TC3-09	IA	15	15	1
TC3-10-A	RIA	20	20	1
TC3-10-B	RIA	5	5	1
TC3-11	RIA	10	10	1
TC4-02	RIA	4	4	1
TC4-03	RIA	5.5	5.5	1
TC4-04	RIA	8	4	2
TC5-03	RIA	2	2	1
TC5-06	RIA	2	2	1
EC-01	CSA	1	1	1
SRC	RIA	10	10	1

[134] The final budgets awarded to actions implemented through the Call for Proposals may vary by up to 20% of the total value of the indicative budget for each action.
[135] The Executive Director may decide to open the call up to one month prior to or after the envisaged date of opening.
[136] The Executive Director may delay the deadline by up to two months. The deadline is at 17.00.00 Brussels local time.

Topic	Type of Action	Budgets (EUR million)	Expected EU contribution per project (EUR million)	Number of projects expected to be funded
Opening[137]: 01 March 2022 Deadline[138]: 20 September 2022				
TC1-03	RIA	4	2	2
TC1-04	RIA	6	6	1
TC1-07	IA	18	18	1
TC1-10	IA	20	20	1
TC2-02-B	RIA	2.5	2.5	1
TC2-05-A	RIA	3	3	1
TC2-05-B	RIA	3	3	1
TC2-07-A	RIA	6.5	6.5	1
TC3-08	IA	7	7	1
TC3-01	RIA	7	3.5	2
TC4-01	IA	7	7	1
TC5-01	CSA	1	1	1
TC5-04	RIA	3	3	1
FCH2-JU-02-A	IA	25	25	1
FCH2-JU-02-B	IA	8	8	1

Through their participation in projects funded under this call and in accordance with point (d) of Article 28(3) of Council Regulation (EU) 2021/2085, Title II, it is estimated that an additional 61 million EUR in-kind contributions will be provided by private members, constituent entities or the affiliated entities of either, participating in the indirect actions published in this call.

In accordance with Articles 11(1), point (b), and 78 (1) of Council Regulation (EU) No 2021/2085 the estimated value of the costs incurred by the private members, constituent entities or the affiliated entities of either, in implementing additional activities (referred to as In-Kind in Additional Activities (IKAA)) is set out in the 2022 Additional Activities Plan, annexed to this document

Call management and general conditions

This section sets the general conditions applicable to calls and topics for grants under this Annual Work Programme. It also describes the evaluation and award procedures and other criteria.

The call included in this Work Programme, including evaluation and award procedures, will be managed according to and the proposals should comply with the Call conditions below

[137] The Executive Director may decide to open the call up to one month prior to or after the envisaged date of opening.

[138] The Executive Director may delay the deadline by up to two months. The deadline is at 17.00.00 Brussels local time.

and with the General Annexes to the Horizon Europe Work Programme 2021–2022[139] that shall apply mutatis mutandis to the call covered in this Annual Work Programme (with the exceptions introduced in the specific topic conditions). There is no derogation from the Horizon Europe Rules for Participation.

Admissibility conditions	The conditions are described in General Annex A.
Eligibility conditions	The conditions are described in General Annex B.
Financial and operational capacity and exclusion	The criteria are described in General Annex C.
Award criteria	The criteria are described in General Annex D.
Documents	The documents are described in General Annex E.
Evaluation Procedure	The procedure is described in General Annex F.
Legal and financial set-up of the Grant Agreements	The rules are described in General Annex G.

If a topic deviates from the general conditions or includes additional conditions, this is explicitly stated under the specific conditions for the topic.

Admissibility conditions: The conditions are described in Annex A of the General Annexes to the Horizon Europe Work Programme 2021–2022 which shall apply mutatis mutandis to the actions covered in this Work Programme.

One condition applicable to all topics in this Work Programme concerns the obligation to include a plan for the exploitation and dissemination of results including communication activities, unless provided otherwise in the specific call conditions.

Additional conditions

- For all Innovation Actions the page limit of the applications are 70 pages.

Eligibility conditions: The conditions, including countries eligible for funding, type of actions and definition of TRL are described in Annex B of the General Annexes to the Horizon Europe Work Programme 2021–2022 which shall apply mutatis mutandis to the actions covered in this Work Programme.

Additional conditions

- For some topics, in line with the Clean Hydrogen JU SRIA[140], an additional eligibility criterion has been introduced to limit the Clean Hydrogen JU requested contribution mostly for actions performed at high TRL level, including demonstration in real operation environment and with important involvement from industrial stakeholders and/or end users such as public authorities. Such actions are expected to leverage co-funding as commitment from stakeholders. It is of added value that such leverage is shown through the private investment in these specific topics. Therefore, proposals

[139] https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/horizon/wp-call/2021-2022/wp-13-general-annexes_horizon-2021-2022_en.pdf

[140] See section 5.3. 'Types of action: specific provisions and funding rates' of the Clean Hydrogen JU Strategic Research and Innovation Agenda 2021 – 2027

requesting contributions above the amounts specified per each topic below will not be evaluated:

Additional eligibility condition: Maximum contribution per topic
TC1-06
TC3-05
TC3-09
TC4-01
FCH JU-02-A
FCH JU-02-B

- For some topics, in line with the Clean Hydrogen JU SRIA[141], an additional eligibility criterion has been introduced to ensure that one partner in the consortium is a member of either Hydrogen Europe or Hydrogen Europe Research. This concerns topics targeting actions for large-scale demonstrations, flagship projects and strategic research actions, where the industrial and research partners of the Clean Hydrogen JU are considered to play a key role in accelerating the commercialisation of hydrogen technologies by being closely linked to the Clean Hydrogen JU constituency, which could further ensure full alignment with the Strategic Research and Innovation Agenda of the Industry and the SRIA[142] of the JU. This approach shall also ensure the continuity of the work performed within projects funded through the H2020 and FP7, by building up on their experience and consolidating the EU value-chain. This applies to the following topics:

Additional eligibility condition: Membership to Hydrogen Europe/Hydrogen Europe Research
TC1-06
TC1-07
TC1-10
TC2-10
TC3-05
TC3-09
TC4-01
FCH JU-02-A
FCH JU-02-B
SRC

- For topic one topic the following additional eligibility criteria have been introduced to allow African countries to i) participate in proposal, ii) be eligible for funding and iii)

[141] see section 5.2. 'Conditions for participation and eligibility for funding' of the Clean Hydrogen JU Strategic Research and Innovation Agenda 2021 – 2027

[142] for further details, see section 5.2 of the Clean Hydrogen JU SRIA

ensure a sufficient geographical coverage of the African continent. This concerns the following topic:

Additional eligibility condition: Participation of African countries
EC-01

Manufacturing Readiness Assessment

- For some topics a definition of Manufacturing Readiness Level has been introduced in the Annexes of the Annual Work Programme. This is necessary to evaluate the status of the overall manufacturing activities included in the following topics:

Manufacturing Readiness Assessment
TC1-03
TC4-01

Financial and operational capacity and exclusion criteria: The criteria is described in Annex C of the General Annexes to the Horizon Europe Work Programme 2021–2022 which shall apply mutatis mutandis to the actions covered in this Work Programme.

Award criteria: The criteria, including threshold(s), scoring and weighting, is described in Annex D of the General Annexes to the Horizon Europe Work Programme 2021–2022 which shall apply mutatis mutandis to the actions covered in this Work Programme.

Documents: The documents including the submission of proposals are described in Annex A of the General Annexes to the Horizon Europe Work Programme 2021–2022 which shall apply mutatis mutandis to the actions covered in this Work Programme.

Evaluation procedure and ranking: The entire evaluation procedure[143] and ranking are described in Annex F of the General Annexes to the Horizon Europe Work Programme 2021–2022 which shall apply mutatis mutandis to the actions covered in this Work Programme.

Exceptions:

- For some topics in order to ensure a balanced portfolio covering complementary approaches, grants will be awarded to applications not only in order of ranking but at least also to one additional project that is / are complementary, provided that the applications attain all thresholds

Exemption to evaluation procedure: complementarity of projects
TC1-02
TC1-03
TC1-08
TC2-13
TC3-01
TC3-02

[143] including indicative timetable for evaluation and for signature of the grant agreement

TC3-06
TC4-04

Seal of Excellence

- For one topic the ‘Seal of Excellence’ will be awarded to applications exceeding all of the evaluation thresholds set out in this Annual Work Programme but cannot be funded due to lack of budget available to the call. This will further improve the chances of good proposals, otherwise not selected, to find alternative funding in other Union programmes, including those managed by national or regional Managing Authorities. With prior authorisation from the applicant, the Clean Hydrogen JU may share information concerning the proposal and the evaluation with interested financing authorities, subject to the conclusion of confidentiality agreements. In this Annual Work Programme ‘Seal of Excellence’ will be piloted for topic

Seals of Excellence is applicable to the following topics:
FCH JU-02-A
FCH JU-02-B

<u>Legal and financial set-up of the grant agreements:</u> The Legal and financial set-up of the grant agreements[144] including funding rates are described in Annex G of the General Annexes to the Horizon Europe Work Programme 2021–2022 which shall apply mutatis mutandis to the actions covered in this Work Programme.

In addition to the standard provisions, the following specific provisions in the model grant agreement will apply:

Intellectual Property Rights (IPR), background and results, access rights and rights of use (article 16 and Annex 5 of the Model Grant Agreement (MGA)).

- An additional information obligation has been introduced for topics including standardisation activities: ‘Beneficiaries must, up to 4 years after the end of the action, inform the granting authority if the results could reasonably be expected to contribute to European or international standards’. These concerns the topics below:

Additional information obligation for topics including standardisation activities
TC2-12
TC3-06
TC5-02
TC5-04
TC5-06

- For all topics in this Work Programme Clean Hydrogen JU shall have the right to object to transfers of ownership of results, or to grants of an exclusive licence regarding results, if: (a) the beneficiaries which generated the results have received

[144] Including Starting date & project duration, Milestones and deliverables, Form of grant, funding rate and maximum grant amount, Budget categories and cost eligibility rules, Reporting & payment arrangements

Union funding; (b) the transfer or licensing is to a legal entity established in a non-associated third country; and (c) the transfer or licensing is not in line with Union interests. The grant agreement shall contain a provision in this respect.

Full capitalised costs for purchases of equipment, infrastructure or other assets purchased specifically for the action

- For some topics, in line with the Clean Hydrogen JU SRIA[145], mostly large-scale demonstrators or flagship projects specific equipment, infrastructure or other assets purchased specifically for the action (or developed as part of the action tasks) can exceptionally be declared as full capitalised costs. This concerns the topics below:

Exceptional declaration of full capitalised costs
TC1-06
TC1-07
TC1-10
TC2-10
TC3-05
TC3-09
TC4-01
FCH JU-02-A
FCH JU-02-B

<u>Indicative timetable for evaluation and for signature of the grant agreement:</u>

Unless otherwise stated in the specific call conditions, the timing for evaluation and grant preparation is as follows:

- information on the outcome of the evaluation: around 5 months from the deadline for submission;
- indicative date for the signing of grant agreements: around 8 months from the deadline for submission.

Common elements applicable to the topics in the Call

EU competitiveness and industrial leadership

In line with the activities started already in the FCH 2 JU, the Clean Hydrogen JU will continue to work to reinforce the European supply chain of critical key components by e.g. a higher range of common/standardised parts to be produced in EU and H2020 Associated Countries, and to enable start investments in production facilities for further ramp-up in these markets.

All topics included in the Call are expected to contribute to EU competitiveness and EU industrial leadership by supporting a European value chain for hydrogen and fuel cell systems and components.

Opportunities for synergies

[145] See section 5.3. 'Types of action: specific provisions and funding rates' of the Clean Hydrogen JU Strategic Research and Innovation Agenda 2021 – 2027

The EU's Recovery and Resilience Facility (RRF) aims to mitigate the economic and social impact of the coronavirus pandemic, to address structural challenges in the member states and to make European economies and societies more sustainable, resilient and better prepared for the opportunities of the green and digital transitions. Applicants are encouraged to consult the national recovery and resilience plans in order to identify specific mentions of synergies with Horizon Europe and to detect further opportunities for complementarity between the plans' rich R&I portfolio and the Framework Programme.

Specific opportunities for synergies with other partnerships and programmes have been included the topic description where relevant.

Contribution to the monitoring framework of the Clean Hydrogen JU

For the purpose of monitoring technology progress against state-of-art, but also to identify how each of the projects contributes to the Clean Hydrogen JU targets, objectives and indicators described in the SRIA, supported projects shall report directly or indirectly on an annual basis in a secure online data collection platform managed by the Clean Hydrogen Joint Undertaking during the course of Horizon Europe. The reporting shall consist of filling in the template questionnaire(s) relevant to the project content (and the technology development and TRL). The projects will need to submit all information included the questionnaire(s), unless they request and receive an exception from the Programme Office. The information is submitted by default as public, but the projects can request for certain fields to be considered as "confidential"[146] except for the fields that constitute or directly inform KPIs of the Clean Hydrogen JU. The submission of the questionnaire(s) shall be integrated as a specific annual deliverable in the grant agreement. An indicative template questionnaires can be consulted online[147].

Guarantees of origin of hydrogen

For some of the topics involving Innovation Actions and related successful actions it is expected that Guarantees of origin (GOs) will be used to prove the renewable character of the hydrogen that is produced/used. In this respect consortium may seek out the issuance/purchase and subsequent cancellation of GOs from the relevant Member State issuing body and if that is not yet available the consortium may proceed with the issuance/purchase and cancellation of non-governmental certificates (e.g CertifHy[148]).

Safety

For all topics a 'safety by design' approach should be considered. In particular, topics involving Innovation Actions and related successful actions, proposals should provide a preliminary draft on 'hydrogen safety planning and management' at the project level, which will be further developed during project implementation (deliverables to be reviewed by the European Hydrogen Safety Panel). Reference documentation and guidance is available on the EHSP webpage[149]. In particular: (i) Safety Planning and management in EU hydrogen and fuel cells projects – guidance document and (ii) simple template for a safety plan

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[146] The Clean Hydrogen JU is committed to respect data confidentiality according to the conditions setup by the Grant Agreement and will only use them in the respect of this attribute: confidential data will not be disclosed as such, but only in aggregated form (following a clean-room approach), and in a manner that ensures non-attribution of their source). Progress and findings that can be shown will be made public (normally associated to the Clean Hydrogen JU annual Programme Review exercise).

[147] https://www.clean-hydrogen.europa.eu/knowledge-management/technology-monitoring-trust_en

[148] https://www.certifhy.eu/

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

For topics involving Research and Innovation Actions or Innovation Actions and related successful projects, projects should report any safety-related event that may occur during the project implementation to the European Commission's Joint Research Centre (JRC) dedicated mailbox JRC-PTT-H2SAFETY@ec.europa.eu, which manages the European hydrogen safety reference database, HIAD 2.0, and the Hydrogen Event and Lessons LEarNed database, HELLEN. Projects reporting on safety should report annually either the safety-related events[150]: near misses, incidents, accidents, or the absence of events.

Contribution to Regulation, Codes and Standards

For topics involving Innovation Actions and related successful projects, proposals are encouraged to consider a public report with both the Legal and Administrative Processes (LAP) and the Regulations, Codes and Standards relevant to the technologies and/or applications at the project scope, the barriers and/or gaps identified during the project implementation, and any other relevant information in order to share the lessons learned and provide recommendations to support the update and/or development of suitable and enabling legal and regulatory frameworks for hydrogen and fuel cell technologies and applications.

Contribution to sustainability and circularity

For all topics applicants are encouraged to address sustainability and circularity aspects in the activities proposed. For a number of selected topics this has been included explicitly in the scope. These topics are:

Explicit reference to sustainability and circularity aspects
TC1-01-A
TC1-01-B
TC1-02
TC1-03
TC1-05
TC1-07
TC1-08
TC2-04
TC2-05-A
TC2-05-B
TC2-07-A
TC3-02
TC4-01
SRC

Activities developing test protocols

For all topics, activities developing test protocols and procedures for the performance and durability assessment of electrolysers and fuel cell components proposals should foresee a

[150] Definitions of near-miss, incident, and accident according to EIGA document INCIDENT/ACCIDENT INVESTIGATION AND ANALYSIS SAC Doc 90/13/E

collaboration mechanism with JRC (see section 2.2.4.3 "Collaboration with JRC"), in order to support EU-wide harmonisation. Test activities should adopt the already published EU harmonized testing protocols[151] to benchmark performance and quantify progress at programme level.

International Collaboration

In recognition of the benefits that international collaboration can bring, it will also be promoted via the Calls for Proposals by encouraging international collaboration beyond EU Member States and Horizon Europe Associated Countries.

In particular for topics dealing with hydrogen in the has grid, public acceptance, safety and Hydrogen Valleys, consortia are encouraged to include legal entities established in the countries members/participant[152] in the Clean Hydrogen Mission under MI2.0 under the following topics, without prejudice to the countries eligible for funding set out in Horizon Europe - Work Programme 2021-2022 General Annexes:

Explicit encouragement for International Collaboration
TC2-02-B
TC2-03
TC2-12
TC5-01
TC5-03
TC5-04
TC5-06
FCH JU-02-A
FCH JU-02-B

In addition, the Work Programme addresses cooperation with African countries in topic HORIZON-JTI-CLEANH2-2022 -05-05.

Collaboration with developing world countries supported by the Climate Technology Centre & Network (CTCN) under the UN Environment Programme is also encouraged.

For more information on International Collaboration see section 2.2.6.8 of this document.

[151] https://www.clean-hydrogen.europa.eu/knowledge-management/collaboration-jrc-0_en
[152] For the list of countries which are members/participant to Hydrogen Innovation Challenge, please see: http://mission-innovation.net/our-members/

1.1.3 Calls for tenders and other actions

1.1.3.1 Calls For Tenders

In 2022, the Clean Hydrogen Joint Undertaking will carry out a number of operational activities via calls for tenders (i.e. public procurement) for an indicative amount of **EUR 2.5 million**. These activities will be financed by Horizon Europe. The procurement activities are covering subjects of a strategic nature for the Clean Hydrogen JU, providing input to R&I priority setting and supporting further financing, deployment and commercialisation of renewable hydrogen and fuel cells projects.

For each of the procurements, detailed Terms of Reference will be drafted with European Commission participation. The following indicative list of procurements is currently foreseen:

Subject (Indicative title)	Indicative budget (EUR)	Expected type of procedure	Schedule Indicative
European Hydrogen Observatory *Public procurements foreseen to ensure the smooth and improved replacement of the current FCHO platform by the European Hydrogen Observatory with a foreseen duration of 4 years; the procurement activities include a call for tender for services and the provision of services by the Members in accordance with article 43.4 of the Financial Rules of the Clean Hydrogen JU.* *In close collaboration and complementarity to related activities of private members.*	2,000,000	Open procedure	Q1
Study on sustainable supply chain and industrialisation of hydrogen technologies *Tender study to update the EU manufactures list along the hydrogen value chain technologies, find potential gaps / bottlenecks in the supply and provide mitigation actions. The estimated duration is 18 months.*	500,000	Open procedure	Q2-Q3

The final budgets awarded to actions implemented through procurement procedures may vary by up to 20% of the total value of the indicative budget.