Strategic Energy Technology Plan

TWG Hydrogen

Declaration of Intent

on Strategic Targets in the context of an Initiative for Hydrogen

"Enabling hydrogen because it matters"

9 April 2024

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DECLARATION OF INTENT

This document[1] is intended to record the agreement reached between representatives of the European Commission services, representatives of the EU Member States and SET Plan countries on setting-up a new Implementation Working Group (IWG) on Hydrogen within the revamped SET Plan[2] and setting targets for hydrogen technology development to build a hydrogen economy in Europe by 2050 in accordance with the European Green Deal. The IWG on Hydrogen will ensure close cooperation with representatives from the SET Plan stakeholders most directly involved in hydrogen activities[3].

This agreement follows consultations with stakeholders listed in Annex I as well as a public consultation and three thematic workshops conducted between August and November 2021 under the ERA pilot initiative "Agenda process on Green Hydrogen". It takes into consideration the corresponding position papers from three expert groups (production, transport/infrastructure and market stimulation), feedback from TWG members and supporters, and discussions in the SET Plan Steering Group meeting on 20 April 2023 with the participation of the relevant SET Plan stakeholders.

The stakeholders agree to the ambitious targets contained in this Declaration of Intent in an endeavour to maintain global leadership in the sector, to put forward their best efforts in a coordinated way between public and private sectors, and to jointly address all relevant issues in order to attain the agreed targets.

1 Introduction

1.1 Hydrogen's global importance as an energy carrier, energy storage and feedstock

Hydrogen has long been important as a feedstock in refineries, chemical reactant in industrial processes and fuel in space rockets. Its physicochemical properties also make hydrogen a versatile energy vector. To date, most of the world's hydrogen production is based on fossil fuels (grey hydrogen) using mainly steam reformation of natural gas and partial oxidation or gasification of coal. This means that due to the high carbon dioxide (CO_2) intensity upstream, each tonne of hydrogen produced generates between 10-19 tonnes of CO_2, which is to a large extent released into the environment[4]. According to the International Energy Agency (IEA), only about 1% of the global hydrogen demand of 94 Mt in 2021 was covered by alternative, low-emission technologies, mainly applying carbon capture, utilisation and storage (CCUS). Recent scenarios find that more than 100 Mt of low-emission hydrogen are needed annually by 2030 to meet the net-zero emission target for 2050 compatible with a 1.5 degrees trajectory[5].

Against the backdrop of climate change and energy security, hydrogen produced with renewable energies and low-carbon hydrogen are gaining greater importance in all sectors of our economy nowadays, bringing more flexibility to the energy system and driving industrial decarbonisation together with renewable electricity. Hydrogen production from water electrolysis is state-of-the-art, but 2-3 times more expensive than grey hydrogen. The significant cost reduction required to reach a competitive price level of 1.0 Euro/kg H_2 compared to fossil alternatives mainly depends on low renewable electricity costs, low electrolyser costs and high electrolyser deployment.[6] If scaled up, electrolysis can make a significant contribution to the storage of bulk amounts of renewable energy, thereby providing extensive buffer functions (daily to seasonal) and increasing security of supply. As renewable and low-carbon hydrogen and its derivatives[7] are still scarce commodities, they should be used most notably in sectors where full electrification is not possible, such as energy-intensive industries (e.g. steel, concrete), high-temperature industrial processes, mobility and transport (air, maritime and heavy goods transport) and in the chemical industry (e.g. ammonia, fertilisers, refinery products and others) to accelerate decarbonisation. Power-to-X technologies can be used to produce various fuels and chemicals from hydrogen, carbon dioxide (removed from the air or captured from biogenic sources), nitrogen and surplus renewable electricity, thus enabling the coupling of different sectors and exploiting further mitigation potentials.

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[1] This document has no legally binding character, and does not prejudge the process or final form of any future decisions by the European Commission.

[2] Communication COM(2023) 634 final.

[3] Clean Hydrogen Partnership, Clean Energy Transition Partnership, Hydrogen Europe Research, European Energy Research Alliance, other SET Plan IWGs

[4] IEA, 2019: The Future of Hydrogen. Seizing today's opportunities.

[5] IEA, 2022: Global Hydrogen Review 2022.

[6] IRENA, 2021. Making the breakthrough: Green hydrogen policies and technology costs.

[7] Examples of hydrogen derivatives: ammonia, methanol, methane, e-fuels

However, hydrogen as an end product in a market with unknown users can only gain a competitive advantage if its market price is lower than that of other energy carriers. Integrated hydrogen-based systems, combining renewable or low-carbon production, storage and consumption in the region, can make use of all hydrogen-related advantages and compensate for comparatively higher hydrogen production costs in specific applications. They will be the necessary building block in a sustainable and carbon-neutral economy of the future, particularly, by complementing concentrated production in big base-load power plants and renewable energy fields as well as reducing costs and risks of energy transfers over large distances. Renewable or low-carbon hydrogen as part of local energy ecosystems not only enables local energy communities but also provides for their optimisation as vertically nested subsystems in energy supply. In this way, new hydrogen technologies create new business models and market players on the level of energy communities and prosumers.

In the long term, renewable hydrogen has a crucial role to play in the complete decarbonisation of our economy. It can have environmental and economic advantages over end-of-pipe solutions considering the full life-cycle and external costs for curbing emissions, which are usually borne by the society[8,9]. However, renewable hydrogen can only deliver on its high expectations for climate change mitigation and sector integration if cost-effectiveness, transparent certification worldwide and the involvement of society in the transition to a hydrogen economy are ensured. More research, development, demonstration and communication is therefore needed in all segments of the value chain and on cross-cutting issues, as well as a bundling of European competences and (non-)financial resources to create innovative and sustainable hydrogen solutions.[10]

1.2 EU policy framework and objectives

Europe's hydrogen policy is closely linked with the strategic long-term vision of becoming the first climate-neutral continent by 2050 and achieving, as an interim target, a net emissions reduction of 55% by 2030, compared with 1990 levels, as proclaimed in the **European Green Deal** from 2020 and set out in the **European Climate Law** from 2021. In order to enhance the framework conditions for hydrogen and bring Europe in a leading position, several initiatives and policies exist at EU level, notably the EU's own Hydrogen Strategy and an accompanying European Commission Staff Working Document on research and innovation investments[11]. A further boost for hydrogen is being provided by:

- The manifold policy measures proposed in the **Fit for 55 Package** to ensure that the comprehensive transformation of our economy takes place in a fair, cost-efficient and equally effective way.[12]
- The **REPowerEU plan**, which aims to rapidly reduce dependence on Russian fossil fuels and accelerate the hydrogen economy (**Hydrogen Accelerator**). The EU goals now aim at a domestic production of 10 Mt of renewable hydrogen and an import of the equivalent amount by 2030[13].
- A proposal for a **Net-Zero Industry Act**, which aims to rapidly expand manufacturing capacity for electrolysers and fuel cells to support the clean energy transition and enhance Europe's competitiveness.[14]
- Council Regulation (EU) 2022/2577 on exceptional measures to accelerate the deployment of renewable energies.[15]
- The **European Green Deal Industrial Plan**, which aims to ensure the EU's economy has access to key green technologies and innovative solutions assisting the energy transition to net-zero and thus increasing the EU's autonomy and resilience[16].

[8] Frondel et al., 2004: End-of-Pipe or Cleaner Production? An Empirical Comparison of Environmental Innovation Decisions Across OECD Countries.

[9] Ajanovic et al., 2022: The economics and the environmental benignity of different colors of hydrogen.

[10] Expert groups of the agenda process, 2022. Strategic Research and Innovation Agenda.

[11] Commission Staff Working Document SWD(2022) 15 final.

[12] Communication COM(2021) 550 final.

[13] Communication COM(2022) 230 final.

[14] Communication COM(2023) 161 final.

[15] Council Regulation (EU) 2022/2577.

[16] Communication COM(2023) 62 final.

- The **European Strategic Energy Technology (SET) Plan**, already launched in 2007, which aims at accelerating the development of low-carbon technologies through cooperation. The revamping of the SET Plan offers hydrogen a greater and open part to play as one of the means towards achieving the clean energy transition.

- The **Renewable Energy Directive (RED)**, EU's legal framework to promote renewable energies, provides development targets, definitions and criteria that also apply to hydrogen. The latest version sets a more ambitious renewable energy target that would help to deliver on the European Green Deal and increase energy independence from fossil fuels. According to RED III, the binding target for 2030 raises from 32% (RED II) to at least 42.5%, but aiming for 45%.[17]

- The **Hydrogen and Decarbonised Gas Market Package**, which is a step forward in decarbonising the EU gas market and integrating renewable and low-carbon gases, in particular biomethane and hydrogen, into the existing gas network.[18]

- The **Alternative Fuel Infrastructure Regulation** to increase the number of publicly accessible hydrogen stations to refuel road vehicles along the TEN-T network[19].

- Two **Delegated Acts**, published in 2023 and supplementing RED II to define criteria for renewable fuels of non-biological origin (RFNBO, including hydrogen, ammonia, methanol or e-fuels) and provide a methodology to calculate their greenhouse gas (GHG) emissions savings.[20,21]

- The **EU Taxonomy**, the EU's sustainable finance framework, by setting ambitious technical screening criteria for sustainable hydrogen investments.[22]

- With the **European Hydrogen Bank**, a new support instrument has been designed by the European Commission in 2023 to unlock private investments in hydrogen value chains and close the cost gap to fossil hydrogen. Future supply of renewable hydrogen within and outside the EU will be connected with the demand side via new financing mechanisms.[23]

Moreover, national hydrogen strategies and action plans are currently being presented or under development in many EU countries. The **EU Governance Regulation** from 2018 requires EU countries to develop national long-term strategies and 10-year **National Energy and Climate Plans (NECPs)** in order to show how they intend to meet the EU's 2030 energy and climate targets[24]. As the NECPs are linked with SET Plan objectives, they are valuable resources for keeping track of developments in hydrogen support policies in countries. In 2020, a study examined the plans and found that almost all of them mention the hydrogen's decarbonisation potential taking a mid-to-long-term perspective, but only half of the plans set explicit hydrogen targets, and the entire value chain is rarely addressed.[25,26]

1.3 R&I efforts and hydrogen support mechanisms in the EU

Europe is called upon not only to keep up, but to take the lead in this transformational period through the new **European Research Area (ERA)**. Given the magnitude of the challenge, only a combination of national, EU, bilateral and multilateral funding and support activities can lead to success. Thanks to longstanding efforts in research and innovation on hydrogen, the EU has become a world leader in electrolysers, hydrogen refuelling stations and megawatt-scale fuel cells[27]. More and more European research projects are successfully being implemented and cross-border partnerships established.

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[17] Directive (EU) 2018/2001, Directive (EU) 2023/2413.

[18] Communication COM(2021) 804 final.

[19] Communication COM(2021) 559 final.

[20] Communication COM(2021) 557 final.

[21] Communication COM(2021) 803 final.

[22] Regulation (EU) 2020/852.

[23] Communication COM(2023) 156 final.

[24] Regulation (EU) 2018/1999.

[25] Trinomics, LBST, 2020. Opportunities arising from the inclusion of Hydrogen Energy Technologies in the National Energy & Climate Plans.

[26] Erbach, G., Jensen, L., 2021. EU hydrogen policy. Hydrogen as an energy carrier for a climate-neutral economy.

[27] Communication COM(2020) 301 final.

- The **Clean Hydrogen Partnership (CHJU)**[28] is an institutionalised public-private partnership with a clear business model for managing calls for research and innovation (R&I) projects to be financed under Horizon Europe. It has mobilised more than 1.2 billion Euro from the European Commission (incl. the allocation from the REPowerEU budget for hydrogen valleys) and at least an equivalent amount from private stakeholders for the period 2021-2027 to support hydrogen-oriented R&I activities in Member States and associated countries. These include technology-based collaborative R&I projects as well as small- and large-scale **hydrogen valleys**. Part of the REPowerEU plan and the related Hydrogen Accelerator concept is to double the number of hydrogen valleys to reach about 50 valleys in Europe by 2025[29] and develop minimum 100 hydrogen valleys globally by 2030 under **Mission Innovation**[30]. In order to align the CHJU activities with the policies and actions taken at national and regional level, a **State Representative Group** is involved with an advisory function[31].

- The **Clean Energy Transition Partnership (CETPartnership)**, a multilateral, co-funded partnership of national and regional research, development and innovation (R&D&I) programmes in European Member States and associated countries, strives for better synchronisation and supports the implementation of the SET Plan. For the implementation of the CETPartnership's own Strategic Research and Innovation Agenda, seven **Transition Initiatives (TRIs)** were formed, of which TRI3 (Enabling Climate Neutrality with Storage Technologies, Renewable fuels and CCU/CCS) and TRI 5 (Integrated Regional Energy Systems) in particular have relevance for hydrogen issues.

- Moreover, **Important Projects of Common European Interest (IPCEIs)** in the hydrogen sector have been initiated by European countries to form large, cross-border, integrated projects while limiting possible distortions of competition. Currently three IPCEIs have been approved (H2 Infra, Hy2Tech and Hy2Use) by the Commission and one more is under evaluation (Hy2Move).[32,33]

- Europe's hydrogen industry has joined forces in **Hydrogen Europe**, an association representing more than 520 members[34]. First industrial projects have been launched by important players in the hydrogen industry. The **European Clean Hydrogen Alliance (ECH2A)**, set up in 2020 to support the large-scale deployment of clean hydrogen technologies by 2030, has presented a pipeline of 840 viable investment projects[35] to facilitate the creation of European hydrogen value chains.

- The **European Energy Research Alliance (EERA)**, the **Association of European Renewable Energy Research Centres (EUREC)** and **Hydrogen Europe Research** are helping to bring together the energy research communities in Member States and associated countries. Furthermore, many national and regional initiatives also make a decisive contribution to a prospering hydrogen ecosystem.

Beyond European efforts, international multi-government initiatives such as the **International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE)** and the **Clean Energy Ministerial Hydrogen Initiative (CEM H2)**, coordinated by the International Energy Agency (IEA), and the **Mission Innovation's Clean Hydrogen Mission** are important vehicles to share information and strengthen international collaboration on hydrogen policies, research programmes, projects and standards to build a global hydrogen economy. Last but not least, the IEA's **Hydrogen Technology Collaboration Programme (Hydrogen TCP)**[36] has been providing a comprehensive framework for collaborative R&I work on hydrogen value chains and cross-cutting issues for more than 40 years, including focused analyses and information exchange among its member countries. The **Technology Collaboration Programme on Advanced Fuel Cells (AFC TCP)**, which has a similar mission but focuses strongly on fuel cells, has been supporting the development of fuel cell technologies and their applications at an international level since 1990 through coordinated research and development, systems analysis, modelling and dissemination.

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[28] As per its legal name Clean Hydrogen Joint Undertaking, formerly known as Fuel Cell and Hydrogen Joint Undertaking (FCH JU) under the 7th Framework Programme and Horizon 2020. Hydrogen Europe and Hydrogen Europe Research represent private partners in the CHJU.

[29] Communication COM(2022) 230 final.

[30] Commission Staff Working Dokument SWD(2022) 230 final.

[31] Communication COM(2021) 87 final.

[32] EC, 2023: Internal Market, Industry, Entrepreneurship and SMEs: IPCEIs on hydrogen.

[33] EC, 2024: Press release on IPCEI Hy2Infra.

[34] Hydrogen Europe, 2024.

[35] EC, 2023: Project pipeline of the European Clean Hydrogen Alliance.

[36] IEA Hydrogen TCP, 2023.

2 IWG Hydrogen under the SET Plan

The European Strategic Energy Technology Plan (SET Plan) was developed to boost the transition towards a climate-neutral energy system through the rapid and cost-effective development of low-carbon technologies at European level. It is a key instrument of the European Commission to support Member States and associated countries with the coordination of their national energy research. Since 2015, the SET Plan has been part of the Energy Union's fifth pillar on 'Research, Innovation and Competitiveness' and constitutes an important tool to monitor research results on low-carbon energy technologies and jointly improve guidelines on energy research and innovation funding in Europe.[37,38] In the Integrated Strategic Energy Technology Plan published 2015, ten key actions for research and innovation were presented along which 14 Implementation Working Groups (IWGs) have been formed to developed concrete implementation plans.[39] A new SET Plan has been adopted in 2023 to better reflect the objectives of the European Green Deal and address cross-cutting issues such as digitalisation, circularity, societal need, skills and market uptake of R&I results[40].

2.1 Scope of the IWG on Hydrogen

The Temporary Working Group (TWG) on hydrogen has its origin in the ERA pilot on green hydrogen ("Agenda process on Green Hydrogen") which was launched in 2021. The R&I initiative backed by EU Research Ministers in the framework of the new European Research Area and initiated under the trio presidency of Germany, Portugal and Slovenia was intended to improve cooperation as well as coordination between European Member States, associated/third countries and the European Commission. It brought together stakeholders from industry, research, politics and society to bundle European competences and financial resources and to jointly develop a Strategic Research and Innovation Agenda (SRIA)[41] based on which wide-ranging cooperation should be started.

The TWG believes that concerted action and a boost to hydrogen research and innovation involving and benefiting all European countries is needed to deliver on the EU's ambitions and build a dynamic hydrogen ecosystem as envisaged in the European Hydrogen Strategy[42]. The TWG recognises the different starting conditions in the countries and regions of Europe and the need for technologies that facilitate the transition to a fully carbon-neutral economy. Therefore, supported R&I activities will cover **renewable and low-carbon hydrogen** solutions, as long as the definitions and criteria set out in RED and the supplementing Delegated Acts are met to ensure that hydrogen achieves at least 70% emissions savings.

The TWG defines a broad scope for the future implementation measures by covering the **entire hydrogen value chain**: generation including manufacturing of equipment, storage, transport, distribution and supply of end user. Hydrogen applications include its use for energy storage, as a fuel in the mobility sector and as a feedstock in chemical processes. However, special attention will be paid on hydrogen applications that have a large potential for avoiding CO_2 emissions in hard-to-abate sectors. In line with the revised SET Plan, the TWG will also cover resource aspects such as scarcity of raw materials and recycling.

In addition to more research and innovation in the field of hydrogen technologies, there is also a need to investigate and establish enabling framework conditions for the transition towards renewable and low-carbon hydrogen. Therefore, the scope of the future IWG also extends to non-technical **cross-cutting issues** such as regulation, standardisation, certification, security, education and training, organisational change as well as public awareness and acceptance. In view of the complexity of an integrated energy system and the various socio-economic and environmental implications of hydrogen technologies, it is also emphasised that systematic analyses and a better availability of more recent data are needed to support well-informed decisions.

The focus is on stimulating technology development by taking into consideration the cycle of technology adoption in the market. As it regards technology maturity, **all technology readiness levels** (TRLs) from basic research to full system tests in an operational environment are within the scope. Moreover,

[37] Communication COM(2015) 80 final.

[38] Dufour, E.; Lisi, V.; Robinson, R., 2019: A guide to the SET-Plan: Including the role of the Social Sciences and Humanities.

[39] Communication C(2015) 6317 final.

[40] Communication COM(2023) 634 final.

[41] Expert groups of the agenda process, 2022. Strategic Research and Innovation Agenda.

[42] Communication COM(2020) 301 final.

technological neutrality and diversification are deemed sensible approaches to increase Europe's resilience in a generally uncertain future. Besides electrolysis, other emerging technologies such as thermochemical, photocatalytic or photobiological water splitting could unfold their full potential under the different natural conditions across Europe (on land, offshore) favouring one or the other hydrogen technology in terms of efficiency, sustainability and costs. Countries inside and outside Europe with inconvenient starting conditions for hydrogen today could possibly adopt emerging technologies that mature later more easily in the future and thus contribute to their global diffusion. Therefore, the TWG assumes a **long-term research perspective** until 2050 and supports the creation of a roadmap (with sensible interim stages) for the full transition.

2.2 Cross-thematic cooperation with other IWGs

Hydrogen as a universal energy carrier is already addressed by several existing IWGs under the SET Plan. However, these IWGs focus on specific domains (renewable energy production technologies, integration in the energy mix, specific hydrogen applications, etc.) and do not consider the global hydrogen value chain. An integrated and interdisciplinary approach that satisfies the systemic role and significance of hydrogen is still missing and requires the collaboration of hydrogen experts along the value chain and from all stakeholder groups. In addition, the successful transformation of the energy system requires thoughtful synchronisation of developments in renewable energy generation, energy transport/storage technologies, and hydrogen applications, and therefore a holistic perspective on the role of hydrogen in this system, which can only be taken to a certain extent by the existing, and often highly specialised IWGs. The proposed IWG on Hydrogen aims to connect the so far detached hydrogen areas and will ensure a close collaboration and complementarity with the existing IWGs. A first virtual exchange with other IWGs took place on 5 June 2023. After further coordination with the other IWGs, focus topics of the Hydrogen IWG will be sharpened and possible intersections, synergies but also differences evaluated.

SET Plan progress reports from 2022 and 2023 show that collaborations have already been established between the existing IWGs, mainly in three cross-sectoral themes I: Integration of renewable electricity, II: Integration of renewable heat, III: Circularity and life cycle analysis. Figure 1 shows future cooperation potential as reported by the IWGs, especially in cross-cutting aspects of the energy transition and digital transformation[43]. Five task forces will be established soon to explore cross-cutting issues systematically and support the collaborative developments[44].

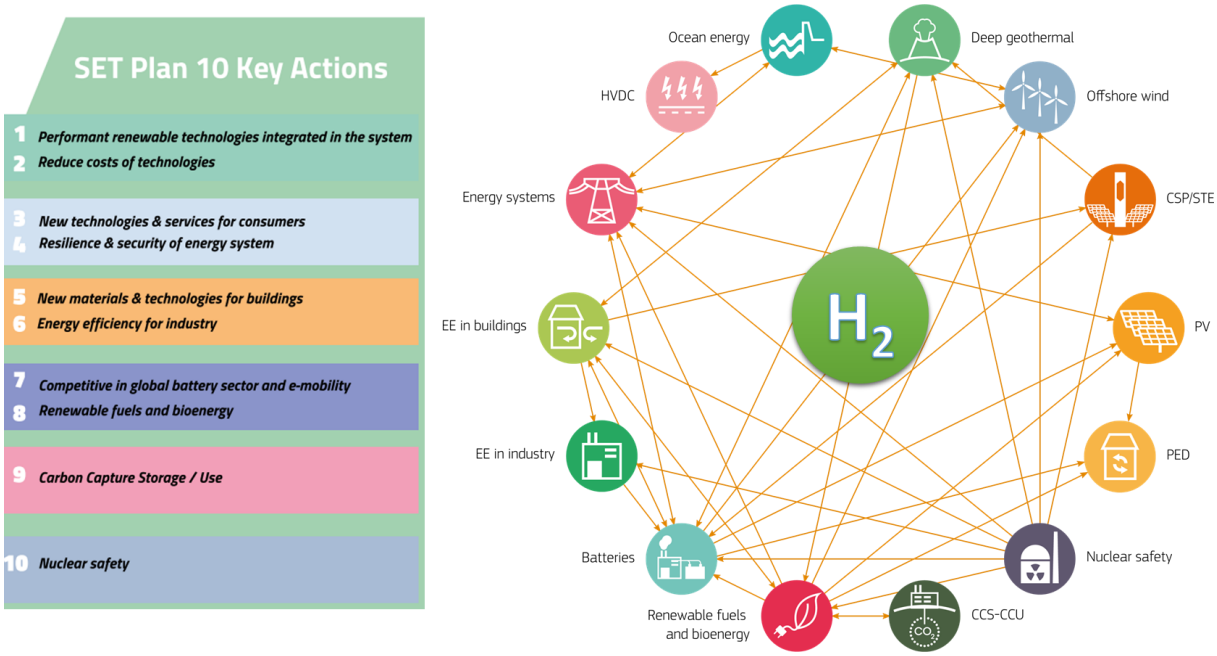

Figure 1: SET Plan key actions and cooperation potential (slightly adapted pictures originate from SET Plan Progress Report 2022 and Dufour, E. et al. 2019).

[43] EC, 2022. SET Plan Progress Report 2022.

[44] EC, 2023. SET Plan Progress Report 2023.

Based on a review of the different implementation plans, we identified potential for cooperation between the IWG Hydrogen and other SET Plan IWGs along the entire hydrogen value chain (see Table 1).

Table 1: Cooperation potential between the H2 IWG and other IWGs (Table is based on Energy Transitions Commission 2021, IEA Hydrogen TCP 2023, SET Plan Implementation Plans and expert opinion).

Production and Sources	Separation and Purification	Storage	Infrastructure, Distribution and HRS	End use and Market stimulation	Cross-cutting issues
• Electrolysis (water) • Electrolysis (steam) incl. direct coupling with industrial processes, waste heat sources • Thermochem. water splitting (e.g. solar, Cu-Cl loop) • Gasification/ pyrolysis (waste, residual biomass) • Plasma gasification (municipal solid wastes) • …	• Membranes • Adsorption • Metal hydrides, • Cryogenic separation • …	• Physical-based (compressed gas, cold/cryo compressed, liquid), • Material-based (adsorbent, liquid organic, interstitial hydrides, complex hydrides, chemical H2) • …	• Pipelines • Smart grids • Points of production, shipping and deployment • Refueling • Liquid organic hydrogen carriers (LOHC) • …	• Industry (Fischer Tropsch process, Haber-Bosch process) • Mobility (fuel-cells, biofuels, e-fuels, H2 ICE) • Power (fuel-cells, combined heat & power, Power-to-X) • Buildings (fuel-cells, micro combined heat & power), • Gas grid • …	• Life-cycle assessment (LCA, S-LCA) • Critical raw materials • Circularity • Safety • Public acceptance • Regulation and standards • Education and training • Policies and roadmaps • …

3 Challenges to address

Following a public consultation and several workshops in the years 2021-2022, the expert groups of the agenda process identified the most important and urgent research demands along the hydrogen value chain. Depending on the degree of maturity, hydrogen technologies need to be researched, further developed, demonstrated under various conditions or adapted to the fields of application. The complexity of the transformation of our energy system and industrial production processes requires comprehensive analyses, interdisciplinary approaches and transnational cooperation. Insofar, the SRIA addresses geopolitical, regulatory, economic, ecological and social aspects in addition to technological challenges. The SRIA concludes with recommendations for the implementation of concrete action items to optimise the European research conditions and unlock the full innovation potential of green hydrogen.

Table 2: Main research demands and action items as presented in the SRIA.

Production	Transport and Infrastructure
• Map existing and potential green hydrogen production capacities in Europe for different timelines (2030, 2040 and 2050) • Map existing and potential needs for green hydrogen for better planning of the production capacities and their distribution • Short-term: Foster technological development, deployment and scaling up of electrolysers coupled with renewable energies • Mid-to-long term: Increase research on emerging hydrogen technologies	• Investigate the demand for a European hydrogen backbone infrastructure and 'hydrogen valleys' • Assess the level of hydrogen-readiness of pipelines and improve gas separation and purification technologies • Find business cases for H_2 transport by rail, ships and trucks • Perform integrated infrastructure modelling to ideally locate electrolysers and storage options (over-/underground), assess the interaction with the electricity grid • Support coordinated infrastructure planning in Europe

Market stimulation

- Identify the most efficient, effective and sustainable hydrogen-specific support measures and link them with the CO_2 reduction potential
- Identify viable business models, develop shared knowledge on reliable key performance indicators and stimulate energy communities and 'prosumers' to invest in hydrogen systems
- Improve the competitive factors of storage systems
- Create uniform international and European framework conditions for green hydrogen and identify credible certification schemes

Cross-cutting topics

- Establish a common technical, regulatory and legislative framework on integrated energy systems
- Measure the carbon footprint of H_2 in each step of the value chain (CO_2 product footprint)
- Develop mechanisms to internalise negative externalities in energy prices and concepts to return money to people and communities
- Apply systems analysis to better understand the interrelationships in an integrated energy system
- Implement pan-European demonstration activities and information campaigns
- Foster education in hydrogen technologies at all levels incl. upskilling and reskilling training

Action items

1. A strong innovation ecosystem for green hydrogen has to be built based on existing or optimised structures. It is vital to accelerate processes by defining the regulation and developing technologies simultaneously.
2. A European digital platform should contain H_2 projects, market layers, trend analyses and official documents of EU Member States. It could be linked with the existing databases such as TRUST.
3. Trusting European and international partnerships and joint action by countries are needed to leverage research funding and increase visibility. The countries' different starting conditions are to be considered for the transition.
4. For an active involvement of Member States and national authorities, a constant dialogue with the EU Commission and other stakeholders in defined hydrogen-related areas is needed to keep the process ongoing and create real impact, e.g. via EU Council Presidencies.
5. The timing of R&I activities and infrastructure setup in European countries needs to be synchronised. A coordinated approach allows for bridging regional 'technology gaps', distributing responsibilities and avoiding duplication of efforts.

However, challenges associated with the establishment of an integrated hydrogen economy are broader than intensifying research activities alone. A successful market diffusion of hydrogen solutions in all economic niches is influenced on different levels and requires a new holistic approach and clear understanding of the role of hydrogen in the future energy system.

- **Policy**: The profound changes entailed in the green transformation of our energy system require a pan-European approach. Due to the inherent structure of the European Union, which is characterised by shared responsibilities between EU institutions and Member States, close coordination is crucial for establishing beneficial framework conditions for hydrogen. In order to implement the impulses arising from the SET Plan and IWG in all European countries, the varying starting conditions must be respected and sophisticated dissemination strategies and concepts need to be developed with the active involvement of key stakeholders.

- **Economy**: Renewable and low-carbon hydrogen are not yet competitive to conventional hydrogen. Their competitiveness largely depends on low renewable energy prices and production costs. Many expectations to reduce production costs are linked to technological development and economies of scale. Apart from financing R&I, manufacturers of hydrogen technologies face challenges in scaling up their production when it comes to financing raw materials and intermediate products, entering new markets as well as minimising liability risks. To alleviate entrepreneurial risks of manufacturers and project developers, private funds become relevant. However, sufficient experience with the new technologies under real-life operating conditions is still missing. The European Hydrogen Bank will support the creation of an initial market and bring more investment security. New market-based hydrogen price indices such as HYDRIX will help to increase the price transparency. In foreign trade, export credit guarantees could be helpful to insure export transactions against economic and political risks. Hydrogen valleys, encompassing all sizes of local hydrogen ecosystems and H_2-based local energy communities (H2LECs), are new players in the market. Complementary to concentrated energy and hydrogen production, they can provide efficient balancing of local energy production (incl. Prosumers) and consumption (e.g. residential buildings, SMEs, larger industries,

public institutions) without large-distance transport of hydrogen. However, there is still the question of how smaller integrated hydrogen-based systems, ranging from a few kW for residential homes to a few MW units for larger industrial companies, could become a viable bottom-up pillar in the European energy and hydrogen supply system.

- **Society**: The participatory approach of the agenda process has to be continued to develop a large hydrogen community across Europe. Considering the perspectives from different stakeholder groups (industry, research, policy, civil society) is decisive to increase public acceptance, promote interest in hydrogen technologies and take informed decisions to the benefit of the whole society. In addition, many well-educated and trained people will be needed to develop and implement competitive, high-quality solutions. This is an aspiration not to be underestimated and requires appropriate stakeholder management.

- **Technology**: Besides the actual development of the core technologies, technological challenges can result from the techno-economic optimisation of a specific use case, fully integrated energy systems or the integration of different technologies along the whole value chain. Other challenges include the increase of energy efficiency and the simultaneous scale up of renewable energies and hydrogen technologies.

- **Ecology**: Renewable and low-carbon hydrogen have the potential to contribute significantly to reducing greenhouse gases. However, like any other technology, it has to be subject to a comprehensive environmental impact assessment along the entire life-cycle to not compromise other sustainability goals. This includes the preservation of natural resources and ecosystems (land, water), the avoidance of (indirect) land use changes, biodiversity conservation and the avoidance of harmful substances. As the majority of a product's environmental footprint is determined in the design-phase, interdisciplinary teamwork is needed from the outset to develop solutions that meet the requirements for eco-design and circularity. The geographical conditions at a facility's location, e.g. relief, land use, protected areas, can affect performance and costs. In a certain environment, a facility may also be more exposed to weather extremes and therefore obliged to invest in adaptation measures to reduce climate risks.

- **Law**: Legislative issues concern, among other things, planning and authorisation, access to existing gas infrastructures, safety requirements, reliable certification and standards, licences, taxes, tariffs and subsidies. So far, these are not yet regulated for the entire hydrogen value chain and therefore cause legal uncertainties.

The IWG will have a very important role in identifying site-specific challenges, uniting the regional efforts and supporting the multiplication and connection of hydrogen valleys, H2LECs and any other European project demonstrating the innovative potential of hydrogen technologies.

4 Overarching goals

The IWG is guided by the overarching goal of creating a thriving hydrogen economy in Europe by 2050. The IWG aims to strengthen the role of hydrogen in the future energy system and unleash its potential for decarbonisation, sector coupling and renewable energy integration. To this end, the activities of the IWG will support the establishment of a strong innovation ecosystem for hydrogen based on European partnerships. This encompasses the joint development, demonstration and accelerated commercialisation of hydrogen technologies to better position Europe in the global market and maintain the competitiveness of key European industries.

The IWG is committed to facilitating the cost-efficient production of hydrogen and the rapid decarbonisation of notably hard-to-abate industries. To truly succeed in becoming carbon neutral in Europe, we have to assume a long-term and holistic perspective in research that ensures openness and flexibility to new technological approaches while improving and expanding already known solutions. At the same time, future solutions must also respect sustainability requirements (protection of climate, ecosystems, biodiversity, culture, etc.) from a life-cycle perspective. For the development of a common European hydrogen market, it is essential to take into account the different starting conditions of the countries and varying speeds of transformation. In addition, the different geographical conditions for hydrogen production can make it difficult to meet the national demand. In the long term, however, the entire hydrogen value chain will have to be based on renewables.

Renewable and low-carbon hydrogen must play an important role in future energy research to become the economic engine of a new, sustainable society. This requires the optimisation of research conditions in all segments of the hydrogen value chain, including cross-cutting issues, across Europe. The IWG is

convinced that effective R&I on hydrogen can best be supported by coordinated action at EU, national and regional level and through the involvement of national authorities. In addition, it is important to accelerate processes by simultaneously defining regulations, developing technologies and setting up infrastructure. To master these challenges and leverage investments in renewable and low-carbon hydrogen, the available human and financial resources of all European countries need to be pooled.

The IWG represents Member States and associated countries from all over Europe with clear ambitions to accelerate the hydrogen economy. It allows to continue with the inter- and transdisciplinary expert community formed in the ERA pilot initiative and the joint implementation of research priorities declared in the SRIA. In this way, the trustful R&I cooperation in Europe can be further strengthened and additional funding sources for hydrogen exploited. For the future, it will be important to monitor the stakeholder involvement in terms of interests and countries represented. As the IWG aims to become a stimulator for more R&I in hydrogen, it is crucial to provide countries with up-to-date information and help them with the implementation of support measures.

The IWG will ensure that the implementation plan will be developed in synergy with other relevant hydrogen initiatives carried out under Horizon Europe, for instance through the Clean Hydrogen Partnership and its State Representative Group, the Horizon Europe main work programme, mostly under pillar II Cluster 5 and under the European Innovation Council (EIC), as well as the hydrogen-related activities carried out by the CETPartnership. Existing support mechanisms will be used where available for the implementation of R&I actions. In addition, the Hydrogen IWG supports the goals of the European Commission, Hydrogen Europe, Hydrogen Europe Research and S3 European Hydrogen Valleys Partnership to build regional hydrogen networks and establish strong interconnections between hydrogen valleys.

The IWG aims to regularly observe the ongoing and future developments (e.g. funding programmes, support measures, projects) at the national level to identify possible synergies in activities, also drawing on the mapping results of other initiatives such as the CHJU's State Representative Group. The IWG will support the exchange of information with initiatives such as HyENet to contribute to transparency and informed decision-making at EU and country level. For the successful implementation of the IWGs research activities, all available instruments are used which are suitable for the respective research challenge and support transnational collaborations, such EERA, CHJU, CETPartnerhship, EU Funds, etc., and also on international level, such as Eureka and Mission Innovation (see Section 1.3).

In order to leverage private investments in hydrogen, the IWG supports the utilisation of other financial mechanisms at national and regional level (provided by National Promotional Banks, National Research Councils, Science foundations, etc.), and facilitates international participation in national hydrogen projects.

5 Strategic targets

Strategic targets outlined in this Declaration of Intent should steer R&I actions and guide coordination of the European Commission and Member State funding in areas of hydrogen production, transport/storage and application, as well as cross-cutting issues.

The IWG on Hydrogen is fully committed to contribute to the overarching EU targets laid down in the Green Deal, REPowerEU Plan and Net Zero Industry Act. The IWG also appreciates commitments by the industry, such as the Joint Declaration of Commissioner Breton and the electrolyser industry in 2022 to increase manufacturing capacities in Europe. Further targets as those listed below have been agreed between the members of the TWG, however, it is necessary to further revise them in close cooperation with other hydrogen stakeholders. Likewise, achieving these targets will require coordination of R&I activities in terms of shared responsibilities and efforts between different stakeholders during the implementation phase.

Targets address the entire hydrogen value chain and technologies of different maturity. They should ensure that cost-competitive hydrogen solutions are developed and a high market potential is achieved. From the national perspective, it is important to include further targets in the future that can be controlled and monitored by them. This includes supporting cross-border R&I calls via existing national funding channels or introducing additional R&I calls and programmes by SET Plan countries, if needed, which connect technological, ecological and socio-economic aspects.

Table 3: Agreed strategic targets to which R&I activities supported by the IWG should contribute.

Support the expansion of hydrogen production and transport infrastructure	• Support the production of 10 million tonnes and import of 10 million tonnes of renewable hydrogen by 2030 • Support the increase of the installed electrolyser capacity being deployed to reach at least 100 GW (hydrogen output) by 2030, of which 40% is manufactured in Europe[45] • Increase storage capacity for SET Plan countries (use-case-specific target) • Support the pan-European backbone infrastructure including the connection of hydrogen valleys via corridors • Support the balance between application needs and production capacity at EU scale • Support in meeting the demand for renewable energies for the production of hydrogen
Develop bottom-up hydrogen ecosystems	• Every country should try to have at least one hydrogen valley by 2030 (large or small) • Support the multiplication and connection of hydrogen valleys, H2LECs and any other European projects demonstrating the innovative potential of hydrogen technologies
Increase the market potential	• Achieve a significant market share of renewable and low-carbon hydrogen by 2030 • Reduce production costs of renewable and low-carbon hydrogen to €1.0/kg H_2 • Reduce costs of electrolysers to around €500/kW (depending on technology and capacity) • Support the reduction of renewable energy costs for hydrogen • Overcome legislative issues along the H_2 value chain and support standardisation

As soon as the IWG on Hydrogen is operational, the group will re-evaluate the targets and concretise key performance indicators and the monitoring approach.

6 Next steps

The stakeholders agree to:

- clarify within 6 months any missing details of target values and indicators,
- develop within 9 months a detailed implementation plan for the delivery of these targets,
- determine joint and/or coordinated actions,
- identify the ways in which the EU and national research and innovation programmes and other initiatives could most usefully contribute and what are the most promising frameworks for collaboration,
- identify the contributions of the private sector, research organisations, and universities,
- identify all issues of a technological, socio-economic, regulatory or other nature that may be of relevance in achieving the targets, and
- report regularly on the progress with the purpose to monitor the realisation of the targets and take rectifying action where and whenever necessary.

The stakeholders intend to use the Declaration as the main vehicle for discussing and agreeing on the implementation plan.

[45] Pursuant to the proposal for a Net-Zero Industry Act

Annex I – Composition of the Temporary Working Group

The content of the Declaration of Intent in terms of research demands and overarching goals is based on previous work of the three expert groups of the Agenda Process on Green Hydrogen (the 32 experts are named in the annex of the SRIA[46]). In the course of 2023, statements and descriptions included in the SRIA have been updated and revised to better reflect the recent developments towards a European hydrogen economy. Further people provided input to derive strategic targets and joined preparatory meetings of the TWG. The following list shows all current members and supporters of the Temporary Working Group and indicates their status, i.e. whether they choose to be active members (AM) or correspondent members (CM) for the time being.

The list comprises 18 countries (16 AM, 2 CM) and 7 supporters. It is sorted by country name. The TWG is chaired by Germany, the Co-Chair is yet to be determined.

Table 4: Members and supporters of the Temporary Working Group on Hydrogen.

No	Name	Organisation	Country	Status
1	Arno Gattinger	Republic of Austria, Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology	AUT	AM
2	Sarah Neumann	Republic of Austria, Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology	AUT	AM
3	Peter Raimann	Austrian Energy Agency on behalf of the Austrian Federal Ministry for Climate Action	AUT	AM
4	Lut Bollen	Flemish Government, Department of Economy, Science and Innovation	BEL	AM
5	Karina Angelieva	Ministry of Energy	BGR	AM
6	Daria Vladikova	Bulgarian Hydrogen, Fuel Cell and Energy Storage Association (BGH2A)	BGR	AM
7	Shimon Müller	Ministry of Industry and Trade of the Czech Republic (MPO)	CZE	AM
8	Alexander Meincke	Federal Ministry for Education and Research (BMBF)	DEU	AM
9	Andreas Kerth	Project Management Jülich (PTJ)/Federal Ministry for Economic Affairs and Climate Action (BMWK)	DEU	AM
10	Nadine May	DLR Project Management Agency/Federal Ministry of Education and Research (BMBF)	DEU	AM
11	Cristina Trueba	Ministry of Science and Innovation	ESP	AM
12	Cristina Garrido	CDTI (Spanish Agency for Business Innovation)	ESP	AM
13	Timo Ritonummi	Ministry of Economic Affairs and Employment	FIN	AM
14	Antti Arasto	VTT Technical Research Centre of Finland	FIN	AM
15	Xavier Montagne	Ministry of Higher Education and Research (MESRI)	FRA	AM
16	Tudor Floréa	Ministry of Energy Transition	FRA	AM
17	Antonios Gypakis	Hellenic Republic Ministry of Development and Investments (GSRT)	GRC	CM
18	Athanasios Stubos	INRASTES at National Research Center Demokritos	GRC	CM
19	Csiki Anita	Ministry of Energy	HUN	AM
20	Edina Udvari	Ministry of Energy	HUN	AM
21	Francesco Luca Basile	University of Bologna	ITA	AM

[46] Expert groups of the agenda process (2022): Strategic Research and Innovation Agenda. Key findings and conclusions of the agenda process for the European research and innovation initiative on green hydrogen. Final version.

22	Viviana Cigolotti	ENEA - Italian National Agency for New Technologies, Energy and Sustainable Economic Development	ITA	AM
23	William Christensen	Ministry of Petroleum and Energy	NOR	AM
24	Tor Ivar Eikaas	Research Council of Norway	NOR	AM
25	Nils A. Røkke	SINTEF, EERA	NOR	AM
26	Jakub Kupecki	Institute of Power Engineering – National Research Institute (IPE-NRI)	POL	AM
27	Paulo Partidário	DGEG - Directorate General of Energy and Geology	PRT	AM
28	Carmen M. Rangel	National Laboratory of Energy and Geology (LNEG)	PRT	AM
29	Teresa Ponce de Leão	National Laboratory of Energy and Geology (LNEG), EERA	PRT	CM
30	Gimi A. Rimbu	National Institute for R&D in Electrical Engineering ICPE-CA	ROU	CM
31	Elena Carcadea	National R&D Institute for Cryogenics and Isotopic Technologies - ICSI Rm. Valcea	ROU	CM
32	Zoran Marinšek	Slovenian Academy of Engineering, Competence Centre for Advanced Control Technologies (KC STV)	SVN	AM
33	Maria Nyquist	Swedish Energy Agency	SWE	AM
34	Hanife Tuzcuoğlu	The Scientific and Technogical Research Council of Türkiye (TÜBİTAK)	TUR	AM
35	Mahmut Ateş	The Scientific and Technogical Research Council of Türkiye (TÜBİTAK)	TUR	AM
36	Nikos Lymperopoulos	Clean Hydrogen Joint Undertaking	EU	AM
37	Isabel Cabrita	Clean Energy Transition Partnership, TRI3	EU	AM
38	Luigi Crema	Hydrogen Europe Research	EU	AM
39	Julia Cora	Hydrogen Europe Research	EU	AM
40	Enrico Degiorgis	European Commission, DG RTD	EU	AM
41	Klaudie Mrkusova	European Commission, DG ENER	EU	AM
42	Greg Arrowsmith	EUREC	EU	AM
43	Andrej Misech	EUREC	EU	AM

An initial virtual exchange with other IWGs under the SET Plan took place on 5 June 2023, with nine out of 14 IWGs participating. As a first step, we have started to concretise the potential for cooperation with four IWGs, which is still ongoing (see Table 3). For the further development of the Implementation Plan, it is intended to share information and meet other IWGs on a regular basis, e.g. in virtual meetings, bilaterally (depending on the demand) and at the SET Plan conference, European Hydrogen Week, etc.

Table 5: Collaborating SET Plan IWGs.

No	IWG	Contact	Topics
1	Bioenergy and Renewable Fuels	Timo Ritonummi, Ministry of Economic Affairs and Employment	• Renewable hydrogen production by electrolysis • Renewable fuels for sustainable transport • Reduce costs for renewable hydrogen • Demonstration of high-pressure electrolysis and megawatt-scale electrolysers • Development of business cases for the on-site renewable hydrogen production for refuelling fuel cell vehicles and mechanisms to guarantee the origin of renewable hydrogen
2	CSP-STE	Luisa Revilla, CDTI (Spanish Agency for Business Innovation)	• Production of renewable hydrogen and synfuels/solar fuels • Energy system integration

3	EE in the Industry	Timo Ritonummi, Ministry of Economic Affairs and Employment	• Cement: Mix of biomass and hydrogen for the kiln combustion system • Chemicals: Integrated production of hydrogen with low carbon footprint (e.g. water electrolysis, methane pyrolysis, photo-electrocatalysis); reactor design, efficient heating concepts for methane pyrolysis, photocatalysts and photoelectrodes • Iron & steel: CO_2 emissions avoidance through direct reduction of iron ore using hydrogen • CCU: Re-use of carbon for steel-making by usage of steel mill gases as syngas for fuels or chemical products, the usage of CO and CO_2 (without or in combination with H_2) as a resource allows to reduce the total carbon footprint
4	Wind	Capucine Vannoorenberghe, IWG Wind Secretariat	• Next generation wind turbines with integrated hydrogen conversion • Energy system integration: onshore and offshore PtX • Validated energy systems models for assessing alternative developments of offshore energy transmission systems, incl. electricity and hydrogen

Annex II – Abbreviations

AM/CM	Active Member, Corresponding Member
CCUS/CCU-CCS	Carbon Capture, Utilisation and Storage
CEMH2	Clean Energy Ministerial Hydrogen Initiative
CETPartnership	Clean Energy Transition Partnership
CHJU	Clean Hydrogen Joint Undertaking
CSP/STE	Concentrated Solar Power/Solar Thermal Electricity
ECH2A	European Clean Hydrogen Alliance
EE	Energy Efficiency
EERA	European Energy Research Alliance
EIC	European Innovation Council
ERA	European Research Area
GHG	Greenhouse Gas Emissions
GW/kW	Gigawatt, kilowatt
H2LEC	Hydrogen-based Local Energy Communities
HER	Hydrogen Europe Research
HVDC	High Voltage Direct Current
HyENet	Hydrogen Energy Network
IEA	International Energy Agency
IWG/TWG	Implementation Working Group, Temporary Working Group
IPCEI	Important Projects of Common European Interest
IPHE	International Partnership for Hydrogen and Fuel Cells in the Economy
LCA, S-LCA	(Social) Life-Cycle Assessment
LOHC	Liquid Organic Hydrogen Carrier
Mt	Megatonne
NECP	National Energy and Climate Plans
PED	Positive Energy Districts
PtX	Power-to-X
PV	Photovoltaics

R&D&I	Research & Development & Innovation
RED	Renewable Energy Directive
RFNBO	Renewable Fuels of Non-Biological Origin
S3	Smart Specialisation Strategy
SET Plan	Strategic Energy Technology Plan
SRIA	Strategic Research and Innovation Agenda
TCP	Technology Collaboration Programme
TEN-T	Trans-European Transport Network
TRI	Transition Initiative
TRL	Technology-Readiness-Level

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