Work Plan
Renewable Hydrogen

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approval

Hydrogen TCP

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Acronyms and definitions

A&C-TF: Task Force on general Analysis & Communication

AE: Alkaline Electrolysis

AEM: Anion Exchange Membrane electrolysis

AFC: Advanced Fuel Cells

BC: Biochemical Conversion

KPI: Key Performance Indicator

MCEC: Molten Carbonate steam Electrolysis

PC: Photo-chemical

PEC: Photo(electro)-chemical

PEM: Polymer Electrolyte Membrane electrolysis

R&D: Research and Development

RE-H2: Renewable Hydrogen production

SOEC: Solid Oxide electrolysis

tbd: to be defined

TCB: Thermochemical Conversion of Biomass

TCP: Technology Collaboration Program

TCWS: Thermochemical Water-Splitting

TRL: Technology Readiness Level

Background and Rationale

Current and future energy scenarios foresee a prominent and growing role for green hydrogen to achieve the complete decarbonization of different sectors of the energy system (e.g. electricity, industry, transport). Hence, several countries have undertaken research, development and demonstration programs to support the introduction and integration of renewable hydrogen in the economy; actions are planned on different levels, from basic research on novel production processes, to pilot/demonstration and, finally, to pre-commercial and first industrial deployment initiatives.

Clearly, the above decarbonization strategies rely on secure hydrogen supply from renewable sources. For hydrogen to play a key role in the achievement of climate neutrality, its production will have to be fully decarbonized and the global production capacity increased by orders of magnitude compared to the current levels.

Renewable-powered water electrolysis is currently the most mature approach to green hydrogen production and a significant increase in the deployment of this technology is envisaged within the next 10 years worldwide. However, there are several alternative processes to produce hydrogen from different combinations of renewable energy sources and feedstock (Figure 1) which could complement electrolysis to achieve higher production capacities in a future flexible and resilient energy system. Networking and collaboration between worldwide experts on these processes will foster the advancement of their technology readiness level and the development of a shared approach for their technological assessment, which will help to fully understand the potential and issues of each option.

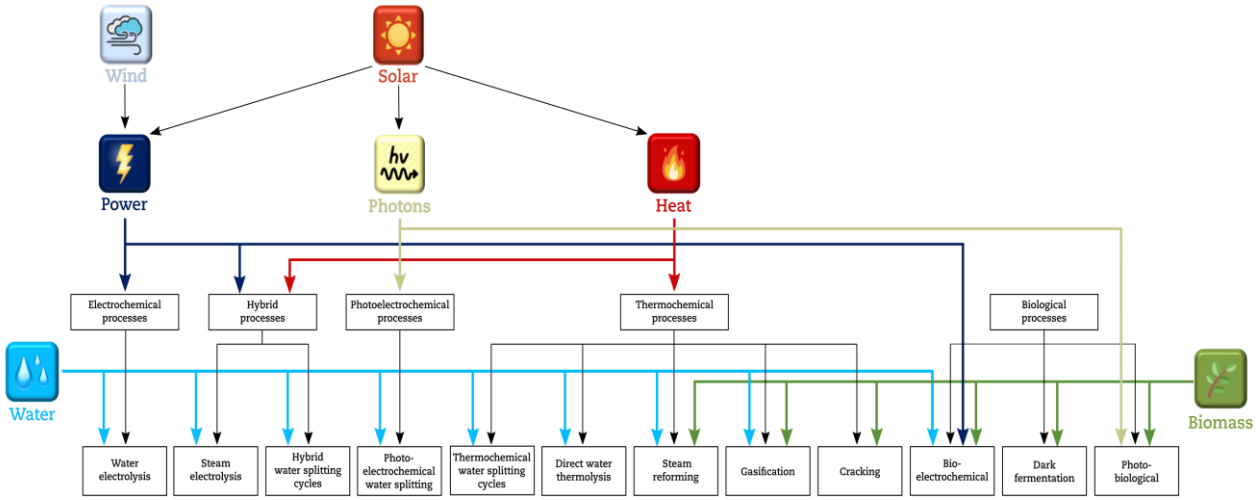

Figure 1. Overview of renewable hydrogen production pathways.

Hydrogen TCP ExCo Members were surveyed and asked to prioritize the different topics from current Tasks in definition. During the first survey in 2021, 85% of ExCo members

marked “Renewable Hydrogen Production” (RE-H2) as a high priority topic for their countries; in the second round done in 2022, 100% of ExCo members marked this topic as high priority.

On the one hand, the multiple option (Figure 1) will provide flexible adaptation of hydrogen production to available (mature & reliable) technologies and local resources. On the other hand, in this stage it is also important to review the different pathways for green (or renewable) hydrogen production to provide decision makers and stakeholders with clear elements to identify the most suitable routes to be implemented in different scenarios. Therefore, it is extremely important to:

1) provide a clear and updated picture of the current state of renewable hydrogen production technologies;

2) provide the elements to assess and compare processes.

The new task takes over the effort of the following previous tasks:

- Task 25 “High Temperature Hydrogen Production Processes” (2007-2011)
- Task 26 “Advanced Materials for Water photolysis” (2008-2011)
- Task 34 “Biological Hydrogen for Energy and Environment” (2014-2017)
- Task 35 “Renewable Hydrogen Production” (2014-2017)

The RE-H2 task may be considered as a follow-up task of Task 35. Compared to Tasks 25 and 35, which only considered water splitting processes, the new task will have an extended scope including processes using renewable carbonaceous feedstock and biological processes previously covered by Task 34, in order to provide a comprehensive view of the green hydrogen production routes.

The above tasks provided relevant assessment of the state-of-the-art of specific Renewable Hydrogen (RE-H2) production technologies. Now, after >5 years from the end of the above tasks, it is important to:

1) update the state-of-the art of RE-H2 technologies;

2) systematically review the different RE-H2 processes;

3) synthesize results in a communicative manner to reach broad stakeholder audience;

4) provide easy-to-handle assessment tools.

The RE-H2 task is fully aligned with the priorities set for the collaborative RD&D theme of the strategic plan 2020-2025. Furthermore, the development of alternative pathways to green hydrogen production based on different renewable sources/feedstocks allows to fully exploit the flexibility of hydrogen as a renewable energy carrier, thus consolidating its role as a link between different energy networks and contributing to the achievement of energy security objectives.

Task Description

The new “Renewable Hydrogen production” (RE-H2) task aims at monitoring the evolution and supporting the visibility of a wide range of renewable hydrogen production technologies as well as providing indications for their technological assessment. The idea is to provide clear and brief updates on the status of different pathways to green hydrogen production, from water-splitting (electrolysis, thermochemical, hybrid) to the conversion of biomass/waste-derived feedstock (biological, thermochemical). Clear indicators will be provided to assess processes with different maturity or rely on different sources in order to enable policymakers and stakeholders to get an updated picture of the status of renewable hydrogen production technologies.

General Scope

The RE-H2 task will cover all aspects that are needed to assess RE-H2 technologies considering the updated state. The following elements define the main scope:

- Data analysis
- Technology assessment
- Techno-economic analysis
- Cross-cutting in cooperation with other TCPs and organizations/partnerships

Objectives

The RE-H2 task will address the following objectives and sub-objectives:

- Monitor the evolution of the RE-H2 production technologies worldwide (or in the Countries participating in the Task),
    - updating the SoA of the renewable hydrogen production pathways, also considering the TRL assessment database already consolidated by the IEA for several technologies
    - providing an overview of different National & International targets: Europe, USA, Japan, Korea, China, Australia, etc. plus relevant targets from industries & stakeholders
- Develop a framework for the technological assessment of the different approaches to RE-H2 production,
    - defining KPIs and methodologies for calculation
    - providing general guidelines for the selection of technologies in specific scenarios
- Support visibility of RE-H2 technologies to foster their deployment,

- creating an updated database of RE-H2 production plants, both R&D and (pre)commercial: success stories, plants in operations/planned, etc.
- disseminating Technology briefs, public reports, and outreach workshops.

Structure

Figure 2 shows structure of the RE-H2 Task. The work plan is divided into five sub-tasks, each implemented by experts of specific technologies who will share key technological information and updates. A "Task Force" group will: (i) collect the data, (ii) synthesize the input and (iii) produce the deliverables that represent the output listed below.

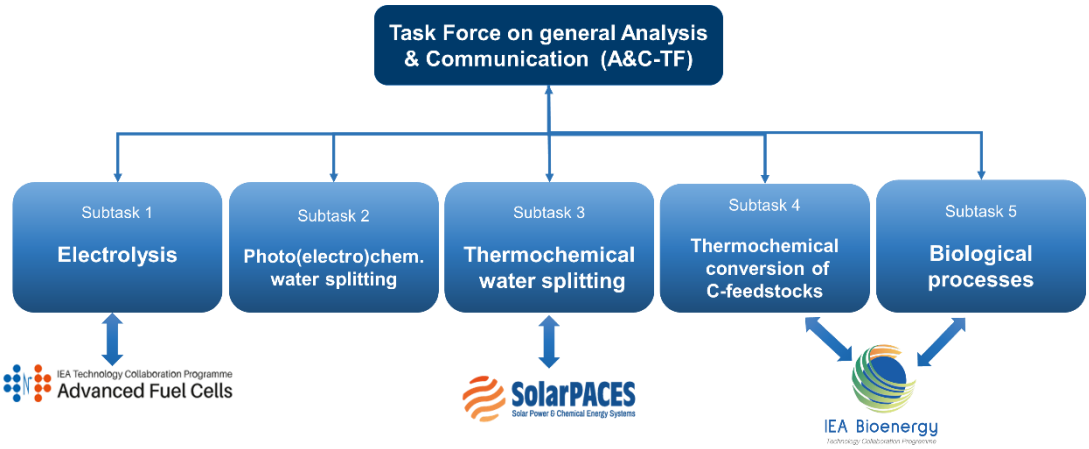

Figure 2. General structure of the RE-H2 task.

- **Subtask 1: Electrolysis**. Expert group to supply updated technology information on Electrochemical water-splitting, considering currently most consolidated approaches like alkaline electrolysis (AE) and Polymer electrolyte membrane (PEM) electrolysis, but also less mature approaches like Anion Exchange Electrolysis (AEM), Solid Oxide steam Electrolysis (SOEC), Molten Carbonate steam Electrolysis (MCEC).
  - Activity 1.1: selection of most relevant technologies/processes at least at TRL 3
  - Activity 1.2: supply of data for the technology briefs (to be updated yearly during the task implementation) according to the format provided by the Task Force (for selected processes) and in agreement with the TRL assessment database currently defined
  - Activity 1.3: supply of data to the Task Force for the definition of KPIs and target values (for selected processes)
  - Activity 1.4: Identification of research priorities (for selected processes)
  - Activity 1.5: Collection of data/information on pilot, pre-commercial or commercial plants
  - Activity 1.6: Cooperation with Advanced Fuel Cells TCP; in the RE-H2 Task processes are analysed at "system level", Advanced Fuel Cells TCP experts can collaborate to review & validate assumptions made for electrolysis components

- Activity 1.7: Techno-economic assessment in different scenarios, identifying the different means to connect the electrolysers with renewable sources (e.g., dedicated renewable power plant, capacity factor, off-peak management, etc.).

- **Subtask 2: Photo(electro)chemical water-splitting**. Expert group to supply updated technology information on photochemical (PC) and photoelectrochemical (PEC) water-splitting.
  - Activity 2.1: selection of most relevant technologies/processes at least at TRL 3 (i.e. proved in the laboratory)
  - Activity 2.2: supply of data for the technology briefs (to be updated yearly during the task implementation) according to the format provided by the Task Force (for selected processes) and in agreement with the TRL assessment database currently defined
  - Activity 2.3: supply of data to the Task Force for the definition of KPI and target values (for selected processes)
  - Activity 2.4: Identification of research priorities (for selected processes)
  - Activity 2.5: Collection of data/information on pilot, pre-commercial or commercial plants
  - Activity 2.7: Cooperation with the European Project SUNER-C and Mission Innovation Sunlight to X.

- **Subtask 3: Thermochemical water-splitting**. Expert group to supply updated technology information on Thermochemical Water-Splitting (TCWS) processes driven with concentrated sunlight, including hybrid processes (i.e., where an electrochemical step is also included) and direct water thermolysis.
  - Activity 3.1: selection of most relevant technologies/processes at least at TRL 3 (i.e. proved in the laboratory)
  - Activity 3.2: supply of data for the technology briefs (to be updated yearly during the task implementation) according to the format provided by the Task Force (for selected processes) and in agreement with the TRL assessment database currently defined
  - Activity 3.3: supply of data to the Task Force for the definition of KPI and target values (for selected processes)
  - Activity 3.4: Identification of research priorities (for selected processes)
  - Activity 3.5: Collection of data/information on pilot, pre-commercial or commercial plants
  - Activity 3.6: Cooperation with Task 2 “Solar Chemistry Research” of the SolarPACES TCP; this cooperation will lead to co-editing respective “Technology Briefs” and the organization of technical workshops
  - Activity 3.7: Cooperation with the European Project SUNER-C and Mission Innovation Sunlight to X.

- **Subtask 4: Thermochemical conversion of C-feedstocks**. Expert group to supply updated technology information on Thermochemical Conversion of Biomass (TCB), including biowastes, considering the different technology approaches, such as: pyrolysis, thermal gasification, partial oxidation, steam reforming of biogas/biofuels,

and cracking, including the option of renewable heat supply (e.g., solar reforming or electrified reforming).

- Activity 4.1: selection of most relevant technologies/processes at least at TRL 3
- Activity 4.2: supply of data for the technology briefs (to be updated yearly during the task implementation) according to the format provided by the Task Force (for selected processes) and in agreement with the TRL assessment database currently defined
- Activity 4.3: supply of data to the Task Force for the definition of KPI and target values (for selected processes)
- Activity 4.4: Identification of research priorities (for selected processes)
- Activity 4.5: Collection of data/information on pilot, pre-commercial or commercial plants
- Activity 4.6: Cooperation with Bioenergy TCP; this cooperation will lead to co-editing respective "Technology Briefs" and the organization of technical workshops.

- Subtask 5: Biological processes. Expert group to supply updated technology information on Biochemical Conversion (BCC) of biomass-derived feedstock, including biowastes, to hydrogen, considering the different technology approaches, such as dark fermentation, photobiological and bio-electrochemical routes.
  - Activity 5.1: selection of most relevant technologies/processes at least at TRL 3
  - Activity 5.2: supply of data for the technology briefs (to be updated yearly during the task implementation) according to the format provided by the Task Force (for selected processes) and in agreement with the TRL assessment database currently defined
  - Activity 5.3: supply of data to the Task Force for the definition of KPI and target values (for selected processes)
  - Activity 5.4: Identification of research priorities (for selected processes)
  - Activity 5.5: Collection of data/information on pilot, pre-commercial or commercial plants
  - Activity 5.6: Cooperation with Bioenergy TCP; this cooperation will lead to co-editing respective "Technology Briefs" and the organization of technical workshops

- Task Force on general Analysis & Communication (A&C-TF): the A&C-TF will be composed of: Task Manager and deputies, Sub-task leaders, and other participants to contribute to the cross-cutting assessment, comparison of processes and dissemination towards policymakers and stakeholders.

  The A&C-TF will specifically coordinate the production and distribution of Technology Briefs (TB), i.e. live documents to be updated regularly during the Task implementation), i.e., concise and clear reports easy-to-handle/understand by non-experts (e.g., policymakers). Figure 3 shows the structure of Technology Briefs, which, for each assessed technology, will be divided into two main parts:

  - Part 1: a 4 pages for general overview (synthetic & communicative for non-expert stakeholders) briefly providing the following informations:
    - Brief description of the technology
    - Terminology: a glossary with clear definitions (e.g., used KPIs, efficiency, LCOH, hydrogen valley, Balance of Plant, etc.)
    - Operation modes and interfaces with Renewable Sources

- Specific materials and resources needs (for plant and feedstock)
- Current development status:
  - TRL assessment
  - Best practices: references on pilot, pre-commercial or commercial plants around the world
  - KPI assessment: current values, including current costs and targets
  - Costs assessment: CapEx and OpEx, factors' impact on the H_2 production cost under representative scenarios
  - Manufacturing readiness level: current level of worldwide production capacity and bottleneck (i.e. any component/material representing a bottleneck for the production of systems)
- Identification of the most suitable application scenarios for the different processes (incl. geographical conditions and plant capacity range)
- Main challenges to be addressed: identification of R&D priorities and KPI targets

- Part 2: more detailed technical insights in an Annex (10-15 pages).

For each technology, TB will provide the following information:

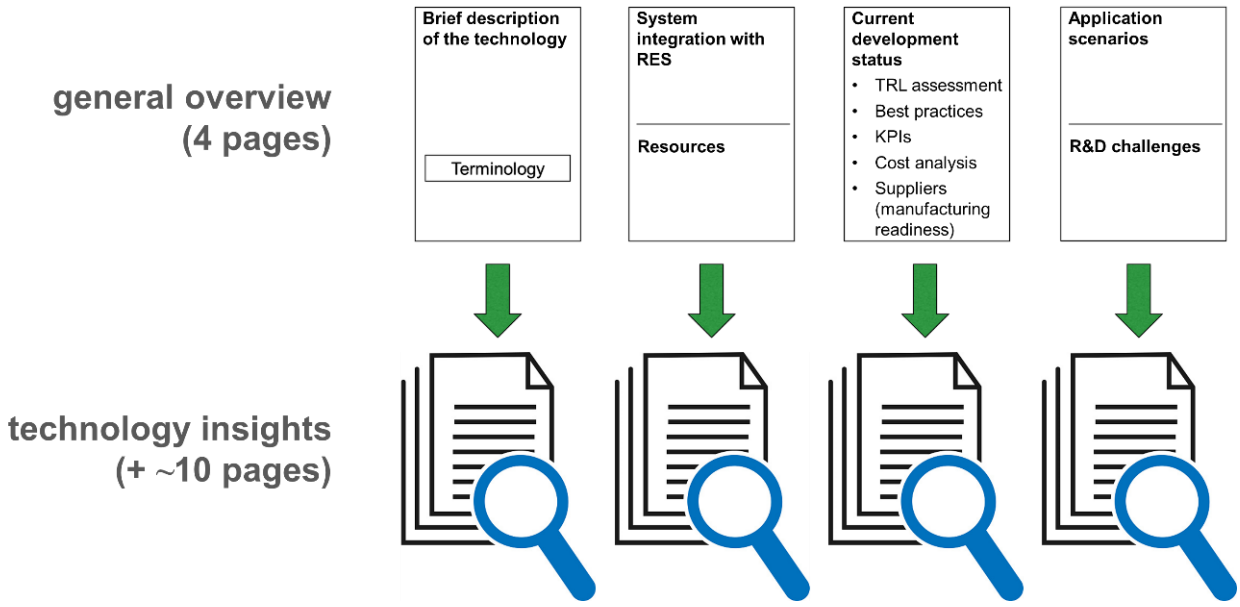

Figure 3. Structure of the Technology Briefs.

Participants

Confirmed /active participants

Participants may cover different roles:

- Task Manager
- two co-Task Managers
- subtask leaders and co-leaders (at least one for each subtask)
- "ambassadors": participants in each subtask providing link with other TPCs
- members of the GA&C-TF (expected: 5-10)
- several experts contributing to subtask groups focused on specific technologies

Current structure:

Role	Name(s) and status
Task Manager	Alberto Giaconia (ENEA, Italy)
co-Task Managers	tbd
Subtask leaders	Bruno Pollet (Univ. of Quebec, Canada) – subtask 1 (tbd) – subtask 2 Alfonso Vidal (CIEMAT, Spain) – subtask 3 Alberto Abánades (Univ. of Madrid, Spain) – subtask 4 Eric Trably (INRAE, France) – subtask 5
Ambassadors linking with other TCPs	n.1 ambassador identified for subtask 1 n.2 ambassadors identified for subtask 3 n.3 ambassadors identified for subtask 4
Members of the GA&C-TF	tbd
Experts	See next section

Interested parties

During the Project Definition Phase this Task received expressions of interest from several experts from different countries as reported in the following Table.

Subtask	leader	n. of experts	n. countries	
	proposed	confirmed	Confirmed	
1. Electrolysis	B. Pollet (CA)	17	10	AU, CA, CN, DK, ES, DE, IT, KR, NL, USA
2. Photo(electro)Chemical water-splitting	tbd	8	6	CA, CN, ES, FR, NL, SE
3. ThermoChemical water-splitting	A. Vidal (ES)	4	4	ES, FR, IT, KR
4. Conversion of C-feedstocks	A. Abánades (ES)	6	3	AU, ES, IT
5. Biotechnologies	E. Trably (FR)	12	10	AU, ES, FR, GR, IT, KR, NO, SE

In total, during the task definition phase more than 45 experts from the following countries expressed interest to join the task in the different subtasks: Australia, Canada, China, Denmark, Spain, Germany, France, Greece, Italy, South Korea, Netherlands, Norway, Sweden, USA.

Timeline

	from July 23 to June 24	from July 24 to June 25	from July 25 to June 26
Preliminary selection of most relevant processes & preparation of SoA Master reports			
Production of first technology briefs			
Update of SoA Master reports			
Update of technology briefs			
Collection of data/information on plants			
Workshops/outreach			