CHAIR
FOR LOW CARBON
HYDROGEN STUDIES

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# ANNUAL REPORT CHAIR FOR LOW CARBON HYDROGEN STUDIES 2021-2022

CURRENT STATE OF THE HYDROGEN SECTOR IN SPAIN - PROJECTS AND REGULATION

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*OCTOBER 25TH, 2022*

## SPONSORS

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# 1. Introduction

## 1.1 Comillas Chair of Hydrogen Studies

It is our pleasure to present the first annual report of the Chair of Hydrogen Studies at Comillas Pontifical University. Our Chair was created as a collaboration between the School of Engineering (Comillas ICAI) and the Faculty of Economics and Business Administration (Comillas ICADE) in July 2021 to contribute to the development of the renewable hydrogen sector in Spain through studies, data collection and analysis, outreach, and informed debate.

The decarbonisation of the economy is one of the great challenges we are facing in our country. In this regard, the use of hydrogen as an energy vector seems to be key for transitioning our energy system:

- Hydrogen enables sector-couple and can be the long-term energy storage needed to manage the volatility of renewable electricity production.
- Hydrogen makes it possible to decarbonise consumption which is difficult to electrify directly, such as certain industrial processes or heavy or maritime transport.
- Hydrogen has the potential to become a relevant new *commodity* in the global energy market for its contribution to the transition towards a green economic model.

The National Integrated Energy and Climate Plan recognise its importance with special emphasis on green hydrogen. The National Hydrogen Roadmap published subsequently stresses the same idea and highlights the opportunities a hydrogen economy might offer for positioning Spain as a leader in producing and exporting renewable energy, promoting i+D and economic growth. However, there are still many unknowns surrounding the possible development of the hydrogen sector.

The Chair of Hydrogen Studies seeks to shed light on these questions through a multidisciplinary approach addressing the entire hydrogen value chain, including technical-economic, regulatory, and financial aspects. Activities aim to contribute to implementing the European and Spanish green hydrogen strategy and achieve climate neutrality no later than 2050.

To achieve its objectives, the Chair relies on the participation of several sponsors that represent the different elements of the hydrogen value chain: Acerinox, BBVA, Carburos Metálicos, Enagás, Cepsa Foundation, Management Solutions, Red Eléctrica de España, and Toyota. Nevertheless, the views expressed in this report do not represent those of any of these institutions, nor do they bind them in any way. Any errors in the accuracy of the information or mistakes are the sole responsibility of the authors.

## 1.2 Objective and report structure

The availability of properly structured and analysed information are prerequisite to a factual public debate and decision-making. The Chair of Hydrogen Studies aims to support and contribute to this process by publishing annual reports providing in-depth analysis of aspects that are highly relevant to the development of the hydrogen sector in the European and national context.

This report, which summarises our findings from the 2021-2022 academic year, is the first edition of this publication, which shall be the first in a series of many others. For this first academic year, we focus on the current state of the Spanish hydrogen sector in a global context. Section 2 presents the most important regulatory milestones concerning hydrogen at a national and international level, while section 3 analyses prospective projects in Spain. Finally, in section 4, we briefly analyse the general status of hydrogen projects in the European Union.

# 2. REVIEW OF RELEVANT POLICY AND REGULATION

# 2 Review of relevant policy and regulation

## 2.1 European scope

### 2.1.1 Regulatory milestones

This section provides an overview of the most important hydrogen-related energy policy and regulatory milestones over the past few months at the European level (see Figure 1).

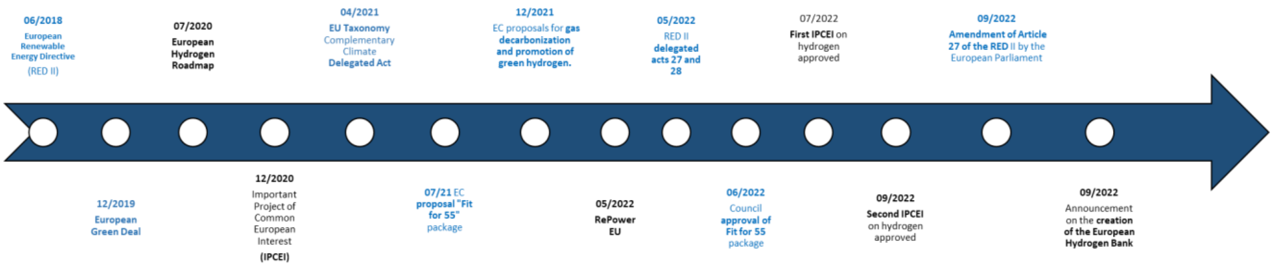



*Figure 1. Regulatory milestones at the European level*

1. **06/2018.** The **European Renewable Energy Directive** provides the framework of the Community's energy policy objectives for renewable energies and their development. This Directive, known as RED II, is a revision of the 2009 Directive and sets a target of 32% final renewable energy consumption by 2030.

2. **12/2019. European Green Deal:** The European Green Deal is a package of policy initiatives with the objective of making the European Union (EU) the first climate-neutral territory by 2050. In this document, the CE mentions hydrogen for the first time as a key to fighting climate change, though it is only mentioned three times in the entire document.

3. **07/2020.** With the publication of the **European Hydrogen Roadmap**, this energy vector becomes one of the central axes of the EU's decarbonisation plan.

4. **12/2020.** Inclusion of the hydrogen sector as an **Important Project of Common European Interest (IPCEI)**[1] .

5. **04/2021.** The EC approved the **"Complementary Climate Delegated Act"** for a European taxonomy in 2021.[2] The Delegated Act refers to renewable or low-emission hydrogen by establishing the GEI emission threshold related to its production. This threshold of $3tCO_2/tH_2$. Hence, it favours renewable green hydrogen production. However, it might be possible for very efficient blue hydrogen production facilities to meet these emission limits set by the European taxonomy.

[1] The IPCEs are instruments to promote the development of strategic industrial value chains in the EU by establishing a cooperation framework between member states.

[2] The EU taxonomy is a classification system that establishes a list of environmentally sustainable economic activities. It aims to link the financial sector to the EU net zero objectives and to redirect capital flows towards sustainable investments.

6. **07/2021.** In 2021, the EC Proposal for the **European "Fit for 55" package** was published, which includes 13 initiatives to reduce greenhouse gas emissions by at least 55% until 2030 compared to 1990 levels. The European Council approved the proposal in June 2022. One of the measures in the "Fit For 55" package is the revision of RED II to extend its application to the industrial sector, a revision that has already been approved by the European Parliament (see regulatory milestone 12).

7. **12/2021.** EC proposal for the **hydrogen and decarbonised gas market package**. This package pursues, among other objectives, the creation of a hydrogen market and the development of specific infrastructures. To this end, it proposes rules on the operation and financing of hydrogen networks, the transparency of gas quality parameters and hydrogen mixtures, the adaptation of natural gas networks for hydrogen transport or unbundling, and non-discriminatory access to the network. To ensure optimal development and management of the hydrogen network, the package calls for the creation of a European Network of Hydrogen Network Operators (ENNOH).

   The proposal also refers to two types of hydrogen: renewable hydrogen and low-emission hydrogen (e.g., blue hydrogen), defined as hydrogen that reduces GEI emissions by at least 70% compared to grey hydrogen. Within the Package, special emphasis is placed on the importance of low-emission hydrogen to increase hydrogen production rapidly and support the energy transition. However, the development of fully renewable hydrogen should not be hindered or delayed to favour low-emission hydrogen. Therefore, priority is given to renewable hydrogen.

8. **05/2022.** In response to Russia's invasion of Ukraine, the **RePowerEU** initiative aims to make Europe independent of Russian fossil fuels well before 2030.[4] This document sets out several measures to reduce Russia's energy dependence, including an upward revision of the targets set by the Hydrogen Roadmap from 5 million tons by 2030 to 20 million tons, of which 10 million tons will be green hydrogen imports.

9. **05/2022.** Publication of proposed **RED II Delegated Acts 27 and 28**. Articles 27 and 28 of the RED II establish the criteria to ensure that the electricity used to produce RFNBOs[5] is of renewable origin. It empowered the EC to develop and unanimously adopt two additional Delegated Acts. These Delegated Acts, originally intended to be published by the end of 2021, were published in May 2022, generating an intense debate due to the strict criteria they specified for the classification of hydrogen as renewable hydrogen. Due to their relevance, each criterion is explained in more detail in section 2.1.2.

10. **07/2022.** Approval of the **first call under the IPCEI for hydrogen.** Under the name "Hy2Tech", 41 IPCEIs were approved with the participation of 4 spanish companies and a value of €5.400 million. This first line of IPCEI covers the entire hydrogen value chain for mobility, encompassing hydrogen generation, fuel cell technology, distribution, storage, transport and end-use applications. The Spanish beneficiary companies are H2B2, Nordex and Sener in hydrogen generation and Iveco in final applications.

[4] See details about RepowerEU: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe_es#acciones-repowereu
[5] Renewable liquid and gaseous fuels of non-biological origin

11. **09/2022**. Approval of the **second call under the IPCEI for hydrogen** Under the name "Hy2Use", 35 IPCEIs from 29 companies with a total value of €5.200 million were approved. This second IPCEI line aims to develop hydrogen-related infrastructure and hydrogen applications at the industrial level. Specifically, "Hy2Use" includes two different and complementary groups of participating projects. The first group targets constructing large-scale infrastructure for hydrogen production, storage, and transport to replace grey hydrogen with renewable hydrogen. The second group focuses on developing new technologies to reduce greenhouse gas emissions in industries such as cement, steel, and glass, which often face major barriers to decarbonisation.

    Among the 35 IPCEI projects, 7 of them are Spanish projects. These are EDP's projects in Aboño, Los Barrios, IAM Caecius project in Aragón; Repsol's projects in the Escombreras Valley (Cartagena) and Bilbao (Petronor) within the Basque Hydrogen Corridor with an electrolysis capacity of 100 MW in both cases, Endesa's joint project with Industrias Químicas del Ebro (IQE) and the two fertiliser production initiatives of Iberdrola and Fertiberia in Puertollano and Palos de la Frontera.

12. **09/2022**. On September 15th, 2022, the European Parliament approved **the revision of RED II**, increasing the percentage of renewable energies in the EU's final energy consumption to 45% in 2030 (compared to the 32% originally proposed). Furthermore, it extends the scope of RED II to the industrial sector, with targets for the share of hydrogen used in the industry of 50% by 2030 and 70% by 2035, excluding consumed hydrogen in the refining industry.

    During the same session, an **amendment** to article 27 was approved by a narrow margin, drastically altering the criteria for producing renewable hydrogen and annulling the additionality criteria set by the previously agreed Delegated Act. This amendment does not affect article 28 and therefore does not modify or nullify the second of the proposed Delegated Acts that may be approved and adopted by the Commission. The changes made by this amendment are explained in more detail in section 2.1.2.

13. **09/2022. Announcement on the creation of the European Hydrogen Bank.** The EC announced in September 2022 that it would double the budget of the Innovation Fund to 3 billion euros to support hydrogen projects. In addition, the Commission announced the creation of a European Bank destined to provide the required financing to connect hydrogen supply and demand in the future[6] . The bank will be partly financed by the resources of the Innovation Fund mentioned above. The announced funding will be accompanied by demand stimulus measures such as the introduction of CCfD at the European level (see section 2.2.3 of this document), the financing of industrial clusters, and the clarification of sustainability criteria [1] .

[6] Available at https://ec.europa.eu/commission/presscorner/detail/en/speech_22_5493

### 2.1.2 Delegated Acts on Articles 27 and 28 of the RED II: additionality criteria and calculation of emissions

#### 2.1.2.1 Delegated Act on Article 27: rules for producing RFNBOs: additionality, temporal and geographical correlation.

The first of the Delegated Acts on the RED II Directive establishes the requirements for hydrogen produced by water electrolysis to be considered fully renewable. The document mentions a transition phase during which some requirements will be relaxed ("grandfathering"), mainly that of temporal correlation until 2027. In summary, two main cases were considered based on the origin of the electricity:

*Table 1. Criteria for the production of fully renewable hydrogen*

| | Case 1: Direct connection | Case 2: electricity taken from the grid under a PPA contract |
|---|---|---|
| **Additionality** | Newly constructed renewable energy facility (<36 months before the electrolyser comes into operation).<br>***Grandfathering***<br>N/A before 2027 | New renewable energy facility (<36 months before the electrolyser comes into operation).<br><br>***Grandfathering***<br>N/A before 2027 |
| **Temporal correlation** | N/A | Hydrogen must be produced:<br>*At the same time that renewable electricity is generated; or<br>*From renewable electricity stored in the same one-hour period in which it was produced under the PPA agreement; or<br>*During a one-hour period in which daily market prices are less than €20/MWh or 0.36 times the price of an allowance for one ton of CO2e.<br>***Grandfathering***<br>Time correlation of one month instead of one hour before 2027. |
| **Geographic correlation** | N/A | The renewable energy facility will be located at:<br>*The same "biding zone" as the electrolyser; or<br>*A neighbouring "bidding zone" with the same or higher prices; or<br>*An adjacent offshore "biding zone". |

#### 2.1.2.2 Amendment to Article 27 of the RED II approved in the European Parliament in September 2022

The conditions established in the previous Delegated Act were significantly modified by an amendment to Article 27 of the RED II approved by the European Parliament, rendering the Delegated Act invalid. The new requirements are considerably laxer. The most relevant changes are the elimination of the additionality criterion at the European level and the hourly time correlation (monthly before 2027), which would be quarterly until 2030. Table 2 briefly summarises the new conditions for producing renewable hydrogen.

*Table 2. New renewable hydrogen procurement criteria*

| | Case 1: Direct connection | Case 2: electricity taken from the grid under a PPA contract |
|---|---|---|
| **Additionality** | N/A | N/A |
| **Temporal correlation** | N/A | Hydrogen must be produced:<br>*From renewable electricity. Producers must sign a PPA for an amount that is at least equivalent to the amount of electricity declared as fully renewable.<br>*The balance between the electricity consumed from the grid and that purchased through PPA will have to be done quarterly until 2030. The EC will decide later on whether the balance should be monthly, quarterly or annual. This new balance will apply to all plants, including those built before 2030. |
| **Geographic correlation** | N/A | The renewable energy production unit will be located at:<br>*The same country as the electrolyser or in a neighbouring country; or<br>*An offshore adjacent "biding zone" to the country where the electrolyser is located or in a neighbouring country. |

The title of the article also changes its name from "Calculation rules for minimum renewable energy shares in the transport sector" to "**Calculation rules in the transport sector and with regard to renewable fuels of non-biological origin regardless of their end use",** making it clear that the rules described for classification as renewable hydrogen apply to all sectors, not only to the transport sector as originally intended.

### 2.1.2.3 Delegated Act on Article 28 establishing a minimum threshold for emission reductions from recycled carbon fuels, as well as a methodology for assessing greenhouse gas emission reductions from renewable liquid and gaseous fuels of non-biological origin and recycled carbon fuels.

The purpose of this Delegated Act is to develop several provisions related to Articles 25 and 28 of the RED II Directive, more specifically:

- Sets the minimum (GHG) emission savings threshold for recycled carbon fuels at 70% (same threshold as the RED II Directive set for RFNBOs).
- It also details the methodology to evaluate the reduction of greenhouse gas emissions from RCFs and RFNBOs. In this sense:
    - It sets as a fossil comparator a value of 94 gCO2eq/MJ. To meet this requirement, the life cycle emissions of RCFs[8] and RFNBOs must be less than 28.2 $gCO_2$ eq/MJ, which in the case of hydrogen, would be equivalent to 3.38 $kgCO_2$ $e/kgH_2$[9] .

[8] Recycled carbon fuels
[9] Based on the lower heating value.

- In addition, it specifies how to determine the carbon intensity associated with the electricity used for hydrogen production. Carbon intensity is assumed to be "zero" when the electricity can be considered completely renewable[10] . Otherwise, the calculation will be made in one of the following ways:
    i. Average carbon intensity in the member state where the hydrogen is produced during the previous calendar year.
    ii. Based on the hours of operation at full load of the electrolyser: if this value is equal to or less than the number of hours in which the marginal price of electricity was set by renewable or nuclear generation in the previous calendar year, the associated intensity will be zero. If this threshold is exceeded, the attributed carbon intensity will be 183 $gCO_2$ eq/MJ.
    iii. Emissions from the marginal electricity generation unit at the time of production.

### 2.1.3 Analysis and conclusions for the European context

If we pay attention to the milestones described in this section, it is easy to appreciate how hydrogen plays an increasingly relevant role in the European energy strategy. From having an almost anecdotal role in the European Green Deal published at the end of 2019, it has become a key energy vector in the objectives set in the framework of the REPowerEU package. Similarly, the new legislative package for the gas sector proposed at the end of 2021 gives hydrogen a central role. It aims to create a legislative framework adapted to the future need for hydrogen production, transport, and storage infrastructure.

The reasons for this evolution in how the importance of hydrogen is perceived are linked to two main factors. On one side, energy policy and regulatory measures have begun to focus on targets beyond 2030, a horizon for which electrification and increased renewable generation are key. As a result, it has become clear that there is a need to find alternatives for all those uses where direct electrification is impossible. Without the decarbonisation of end-uses that cannot be electrified, it will be impossible to achieve emissions neutrality by 2050. On the other hand, the war in Ukraine has exposed the risks of Europe's high energy dependence. This has made the security of supply equally or more important than climate objectives in energy policy. (Renewable) hydrogen is seen as a possible solution or part of the solution to both problems simultaneously.

The latest proposals by the European Commission, specifically the Delegated Act setting out criteria for hydrogen to be renewable, sparked a heated debate as reflected in the more than 300 responses to the public consultation process. Among the responses submitted by stakeholders, there was a wide range of opinions, from those who said that the proposed rules were too lax and would result in increased emissions if hydrogen production capacity were to grow to those who argued that the rules were so complex and restrictive that they would make investments in renewable hydrogen very difficult.

This debate entered a new phase when the European Parliament narrowly approved the amendment to Article 27 of RED II. The amendment eliminates the additionality criterion and makes the time correlation much more flexible. The hourly correlation proposed in the

[10] Electricity consumption within a "bidding zone"will be considered fully renewable as soon as the proportion of renewable generation has exceeded 90% in the previous calendar year.

Delegated Act (for the period after 2027) was one of the most discussed points as it made the production of hydrogen for industrial processes, where a constant supply of hydrogen is required, very complex. It would imply a significant increase in the cost of hydrogen if only dedicated renewable generation is used. The new amendment makes this time correlation quarterly, at least until 2030 when the EC will decide whether the balance will be monthly, quarterly or even annually.

From the Chair, we welcome the flexibility introduced concerning this time correlation. We believe it will lower the cost of hydrogen production by reducing the need for storage facilities, which would cause investment and operating costs to skyrocket in many cases. Furthermore, eliminating the additionality criterion will facilitate faster deployment of hydrogen and the use of excess renewable energy at specific times to produce hydrogen, avoiding spills. However, in the medium and long term, it will be essential to ensure that sufficient renewable electric generation is provided to cover the decarbonisation needs of all sectors, either through direct or indirect electrification.

This decision by the European Parliament cannot be understood without further study of the international context. It may well have been influenced by the publication of the Inflation Reduction Act (IRA) in the United States. We will discuss this publication in more detail in section 2.3, given that it might offer more favourable conditions for hydrogen development.

## 2.2 National context

### 2.2.1 Regulatory milestones

This section will first outline the most important regulatory milestones for the hydrogen economy at the national level (Figure 2). We then discuss the two most important milestones in the national context with greater detail: the first hydrogen project support programs and the development of the guarantees of origin system for hydrogen.

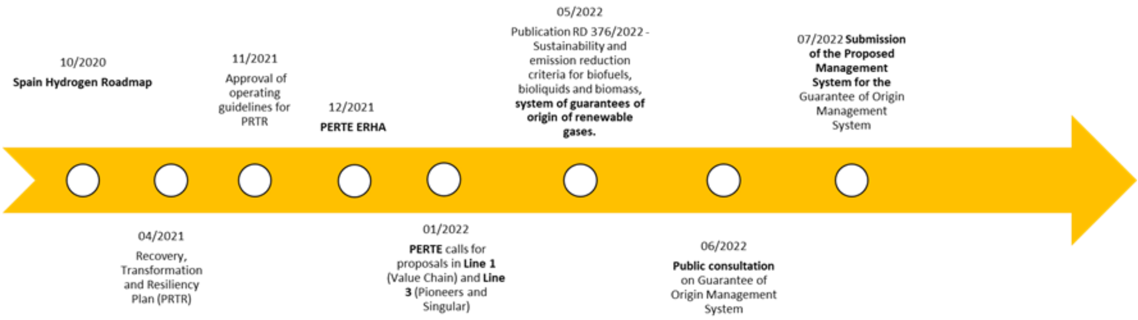



*Figure 2. Regulatory milestones at the national level*

1. **10/2020.** In line with the direction set by the EU Hydrogen Roadmap, the Spanish government published its national roadmap in 2020 entitled "**Hydrogen Roadmap: a commitment to renewable hydrogen**". As its name suggests, the roadmap focuses on deploying green hydrogen as a central tool to achieve climate neutrality.

2. **04/2021.** The Recovery, Transformation, and Resilience Plan was approved a few months later, framed as part of the Next Generation EU recovery plan to recover the European economy after the crisis suffered by the COVID-19 pandemic. This plan refers to hydrogen by describing the main challenges, objectives, and investments related to hydrogen.

3. **11/2021.** The operational bases for the monitoring of the Recovery plan and the funds of up to 140 billion euros for the period until 2026 were approved by the European Commission with a strong concentration of investments in the first phase, covering the period of 2021-2023.

4. **12/2021**. The **PERTE**[11] **ERHA** (for renewable energies, renewable hydrogen, and storage) was approved, allocating 1,555 million euros to hydrogen until 2026.

5. **01/2022.** Publication of the **regulatory bases** for the PERTE aid programs corresponding to action lines 1 and 3. These aid programs are explained in section 2.2.2.

6. **05/2022.** Publication of **Royal Decree 376/2022** regulating the criteria for sustainability and reduction of greenhouse gas emissions from biofuels, bioliquids, and biomass fuels,

[11] In order to channel the funds of the recovery plan, the Spanish government established the Strategic Projects for Economic Recovery and Transformation (PERTE) funding scheme. This is an instrument of public-private collaboration which objective is to promote major initiatives that contribute to the transformation of the Spanish economy.

as well as introducing a **system of guarantees of origin of renewable gases**. This Royal Decree establishes a system of guarantees applicable to renewable gases, which will be designated to the Technical System Manager, in the case of Spain, Enagás.

7. **06/2022.** Motivated by the Royal Decree, Enagás initiated a public consultation for the management procedure of the **system of guarantees of origin of renewable gases** in June 2022**.**

8. **07/2022.** On July 29th, 2022, the proposal for the management procedure for the **system of guarantees of origin for renewable gases** was submitted to the secretary of state. This proposal is explained in detail in section 2.2.3.

### 2.2.2 Calls for hydrogen support under the PERTE ERHA framework

The PERTE ERHA, within the framework of the PRTR, provides funding of €1,555 million to four lines of action:

- Line 1: Promote the innovative and knowledge value chain; measures to support small and medium enterprises (SME) and technology centres.

- Line 2: Creation of a renewable hydrogen cluster for sectoral integration that spatially concentrates production, transformation, and large-scale consumption.

- Line 3: Development of pioneering individual projects that allow the introduction of renewable hydrogen, among others, in additional industrial clusters and isolated energy systems, as well as the integration of renewable hydrogen supply in transport, electricity generation, and thermal uses.

- Line 4: Support actions to integrate the national value chain with the European Community through support for the participation of national companies in European projects and consortiums, including contributions for the participation in IPCEI hydrogen projects.

At the time of writing this report, only two calls for proposals have been published corresponding to lines 1 and 3 (not yet awarded) and a total budget of €400 million. Both lines were announced in 2021 under the Transformation and Resilience Recovery Plan. In 2022 and 2023, funding calls worth €555 million and €600 million should be announced, although, so far, it is unclear which line each of these funding rounds will address.

The call for PRTR grants is compatible with the simultaneous participation of a project in the IPCEI as long as the different instruments are not destined to the same expenditure items.

- **Support programs for the innovative renewable hydrogen value chain within the framework of the recovery, transformation, and resilience plan (line 1).**

Measure number 14 of the PERTE for renewable energies with a total budget of 250 M€ aims to promote the entire hydrogen value chain. The hydrogen value chain is a very broad concept. Hence, investments are divided into four programs that cover projects ranging from researching and enhancing the state-of-the-art to large electrolysis demonstration projects.

| |
|---|
| **Program 1: Capabilities, Technological Advances, and implementation of testing and/or manufacturing lines** |
| Subprogram 1 (a) renewable hydrogen value chain equipment manufacturing centres<br><br>**Budget:** €20M **Minimum investment:** €1M **Maximum aid:** €7.5M per company per project |
| Subprogram 1 b) improvement of capacities linked to R&D<br><br>**Budget:** 10M€ **Minimum investment:** 1 M€ **Maximum aid:** 15 M€ per company per project |
| **Program 2: Design, demonstration, and validation of new hydrogen-powered vehicles** |
| **Budget:** 80M€ **Minimum investment:** 1 M€.<br><br>Vehicles included: Heavy land vehicles (buses and trucks), marine vessels, rail vehicles, logistics machinery, manned aircraft, and ancillary services in airport environments. |
| **Program 3: Large-scale electrolysis demonstrators, innovative renewable hydrogen production projects** |
| Subprogram 3 a) Development of a first electrolyser prototype improving or enhancing the current state-of-the-art, with a budget of 40 million.<br><br>**Budget:** 40M€ **Minimum investment:** 1 M€ **Maximum aid:** 15 M€ per company per project |
| Subprogram 3 b) for the real and effective integration of a large electrolyser in an industrial operational context,<br><br>**Budget:** 60M€ **Minimum investment:** 1 M€ **Maximum aid:** 15 M€ per company per project **Electrolysis capacity:** Greater than 20 MW.<br><br>Subprogram aimed at the industrial sector, ideally towards integrated production-consumption schemes for which the shortest distance between the point of production and consumption will be positively valued.<br><br>The electrolyser must be physically connected to a newly constructed renewable energy production plant, although renewable production itself will not be eligible. In case of opting for a PPA, this contract must be made with newly constructed renewable installations for a minimum duration of ten years. |
| **Program 4: Challenges of basic fundamental research, innovative pilots, and training in key enabling technologies within the value chain** |
| **Budget:** €40M **Minimum investment:** €500,000 **Maximum aid:** €20M per company per project. For training projects, the limit will be €2M. |

Projects will be awarded based on the following award criteria:

- Scalability and replicability
- Technical viability (TRL)
- Economic viability
- Participation of Pymes
- Positive impact on fair transition zones
- Emissions reduction
- Job creation

Once a project has been awarded one of the support schemes, it must be realised within 36 months.

- **Incentives for pioneering and unique renewable hydrogen projects within the framework of the Recovery, Transformation, and Resilience Plan (line 3).**

The 16th measure of the PERTE for renewable energies with a total budget of 150 M€ has the objective of financing first developments in the production, distribution, and consumption of renewable hydrogen as well as those unique projects that allow the validation of new technologies.

Pioneer projects must combine production, distribution, and consumption in the same location. By design, these are small-scale projects at the local level (0.5-20 MW to be financed) to ensure the reliability and operation of the technology as well as favour its subsequent scalability. These projects will mainly be implemented in industries with an already existing demand for hydrogen with greater technological maturity. However, heavy mobility uses could also be financed.

For isolated hydrogen projects, the focus is on innovative applications such as fuel cells in airports, ports or logistics applications. Projects that inject hydrogen into the natural gas grid (blending) or electricity sector applications, such as energy storage or electricity generation in combined cycle power plants, are not eligible.

For eligible projects and unlike the innovative value chain support programs, part of the newly built renewable generation plant will be subsidised as long as the connection between the plant and the electrolyser is direct. Cases in which a PPA model is chosen will not be financed as the renewable production plant has already been constructed and does not imply additional expenditures.

Projects of more than 20 MW will be eligible for support under subprogram 3b) of the renewable hydrogen innovative value chain support program within the recovery, transformation, and resilience plan framework.

### 2.2.3 Procedure for managing the system of guarantees of origin

By RD 376/2022, which regulates the Guarantees of Origin System (GdO) for gas from renewable sources, the Technical System Manager submitted the proposed management procedure to the Secretary of State. The most important questions about this system are answered below.

**What are the guarantees of origin for renewable gases?**

A guarantee of origin is an electronic document whose function is to accredit that gas has been produced with 100% renewable energy, providing added value when it is marketed to end-consumers.

Such GdOs will certify the gas and its quality by differentiating between various types of gases of renewable origin: hydrogen, biogas, biomethane, and other gases. The system will also cover the use of any renewable gas for consumption, export or injection into the gas grid.

**How does the system of guarantees of origin work?**

One GdO corresponds to the net production of 1 MWh of renewable gases taking its higher calorific value; in the case of hydrogen, it would be the equivalent of 25 kg of $H_2$. A digital platform will be created to enable its issuance, transfer, redemption or export to manage the system of guarantees of origin.

To this end, each GdO will contemplate three associated adjustable parameters that will allow its transfer and management: "Holder", "Status", and "Transaction codes". In addition, other non-modifiable parameters will allow each GdO to be unmistakably identified. These are, among others, parameters such as the GdO number, the issuing entity, the type of energy vector, the energy source, the technology, the point of production, and the date of issue.

**Issuance of guarantees of origin**

The calculation of the issuance rights is based on the monthly net accumulated renewable production, subtracting the production facility's own consumption. The registration of a net production of 1 MWh gives the right to issue one GdO, specific for each production point that will be identified by the corresponding code.
In cases where production is based on more than one energy source, the dispatch rights will be linked to each energy source in proportion to its consumption. If energy steams from renewable and non-renewable sources, only the portion of the dispatch fees proportional to the renewable energy consumption share will be issued.

**Transfer of guarantees of origin**

The transfer of GdO is the process by which a guarantee of origin passes from the account of one "issuing holder" to the account of a second "holder or receiver". GdOs can only be transferred up to 12 months after their issuance date and must be transferred in homogeneous packages from the same producer and energy source.

The transfer will be carried out via the platform and under the manager's supervision to verify that the GdOs meet the requirements for transfer. In order to facilitate and promote the GdO market, the platform will have a public tool for announcing account holders' interest in buying and selling GdOs in a non-anonymous way.

**Export/import of GdOs**

Guarantees of origin GdOs can also be exported or imported to agents in the European Union (the document does not mention other territories). The process corresponds to the transfer process of GdOs on a national level and must therefore meet the same requirements: a maximum of 12 months from the date of issue, and the batches must be homogeneous.

The procedure is still uncertain as it depends on establishing the respective European renewable gas guarantee of origin systems currently under development.

**Redemption/export of GdOs**

For redeeming a GdO an energy consumer assigns the guarantee to the energy consumed, granting it a renewable origin. The redemption of GdOs is only allowed for consumptions of the same type, and they may be redeemed up to 18 months after their date of issue. The consumption of each calendar year may be redeemed in the same year and up to March 31st of the following year.

The GdOs coming from self-consumption units will be issued with the status of "redeemed" and cannot be redeemed or transferred. Hence, these GdOs will not be susceptible to monetisation by the producer.

**What happens with blending?**

Blending is a particular case of hydrogen use since it involves blending hydrogen in the natural gas network. For this reason, it is a special case in the GdO's management system. The established solution was to create a new category of gas of renewable origin: Hydrogen B (blending). The process would consist of converting a pure hydrogen GdO to a hydrogen B GdO that could be subsequently redeemed for consumption in the gas system.

**How does the GdO system of renewable gases relate to RED II?**

The proposal for managing the GdO system for renewable gases does not refer to the criteria laid out about the temporal or geographic correlation of RED II. The proposal emphasises that "the objective of the Guarantees of Origin is to demonstrate to the final consumer the renewable origin of their consumption, and in no case constitute proof of sustainability in production". Hence, the additional certification needed to prove compliance with RED II is beyond the scope of this document.

### 2.2.4 Analysis and conclusions for the national context

The previous section demonstrates relevant regulatory advances towards a hydrogen economy in Spain. On one side, the publication of the first calls for hydrogen subsidies under the PERTE ERHA was an important milestone for the sector. These calls were eagerly awaited, as do the high number of expressions of interest previously received by MITERD show. Some changes were introduced to the terms of the calls after public consultation, such as extending the scope of support to hydrogen consumers under certain conditions. However, some of the eligibility requirements could limit the scope or viability of the projects[13] .

[13] Eligibility requirements that could limit the scope of projects include stipulations concerning the size of the projects, the need for direct connection to renewable power or new installation, tight execution deadlines, incentive effects, or others related to off-takers.

It is still too early to know if these conditions have had a relevant impact on participation. When the results of these calls are announced[14], which we hope will be successful, it will be possible to analyse the results and identify aspects to be improved for the future. Likewise, especially for those calls aimed at technologies with lower technology readiness level (TRL), technologies not included in the current calls, such as synthetic fuels or renewable hydrogen production technologies alternatives to water electrolysis, could benefit.

On the other hand, the creation of the GdO system for renewable gases, including hydrogen, appears to be progressing rapidly. It is expected to be in operation in the first half of 2023, approximately one year after the publication of RD 376/2022. At the time of the consultation, there was great uncertainty regarding the discussion at the European level. As shown in the report analysing the results of the public consultation process, many of the questions were related to additionality, time correlation, and geographical correlation criteria of the now invalidated Delegated Act 27 proposal. The GdO manager's response emphasises that the GdO to be issued does not guarantee sustainability certification, arguing that this exceeded the scope of the GoO system. However, their response opened the door to including this information among the optional attributes declared in the GdO. Therefore, recent changes at the European level should not significantly affect the initial proposal of the GdO system.

In conclusion, there have been relevant advances in hydrogen in Spain over the last year. Although such progress is welcome, there is still much to be done in terms of regulation and standards, as well as the design of possible incentives for alternative production and the use cases of hydrogen demonstrating its contribution to decarbonisation. In this regard, the Chair believes it is worth reflecting on relevant international experiences, such as those briefly described in the following section.

## 2.3 Other international experiences

This section briefly describes some of the most relevant international initiatives related to hydrogen promotion in the global context. Firstly, the *Inflation Reduction Act* recently passed in the US is analysed, introducing important economic incentives for producing low-emission hydrogen. Additionally, we take a closer look at contracts for carbon difference, considered a likely tool to promote the use of hydrogen in industrial sectors in other European countries and the EU.

### 2.3.1 The US Inflation Reduction Act (IRA)

On August 16th, 2022, the Inflation Reduction Act (IRA) was passed in the United States, approving $437 billion in spending over 10 years. About $370 billion is earmarked for renewable energies, electric vehicles, and low-emission hydrogen. The following is a summary of the law's provisions related to hydrogen.

Support targets low-emission hydrogen production with life cycle emissions (up to production) of less than 4 $KgCO_2/KgH_2$ without discriminating between production technologies or limitations of additionality, geographical or temporal correlation. Therefore, production routes other than green "electrolysis" hydrogen, such as pink, turquoise or blue hydrogen, could also

[14] The hydrogen support programs were provisionally solved in December 2022 (after the date of publication of this report). The provisional resolution is available on the electronic website of the Institute for Energy Diversification and Saving (IDAE). https://sede.idae.gob.es/lang/.

receive tax credits. Support is provided in the form of either production tax credits (PTC) or investment tax credits (ITC), with the choice of one or the other being at the discretion of the project developers. The amount and associated emissions requirements of these subsidies are shown in Table 3.

*Table 3. Amounts of PTCs and ITCs of the US IRA. Source: S&P Global Inflation Reduction Act [2]*

| Carbon intensity | Emission reduction[15] (%) | Production tax credit (PTC) | Multiplier (x5) | Investment Tax Credit (ITC) |
|---|---|---|---|---|
| **4-2.5 Kg $CO_2$ e/Kg$H_2$** | ~ 60-75 | 0,12 $ | 0,60 $ | 6 % |
| **2.5-1.5 Kg $CO_2$ e/Kg$H_2$** | ~ 75-85 | 0,15 $ | 0,75 $ | 7,5 % |
| **1.5-0.45 Kg $CO_2$ e/Kg$H_2$** | ~ 85-95 | 0,20 $ | 1 $ | 10 % |
| **0.45 Kg $CO_2$ e/Kg$H_2$** | >95 | 0,60 $ | 3 $ | 30 % |

Regarding production incentives, the IRA offers an incentive of up to \$3/kg$H_2$ for 10 years for facilities commissioned before 2030. The base amount is up to \$0.60/kg, which can be increased up to five times based on a multiplier mechanism that would be triggered if certain requirements are met. On one end, these are that the construction of the facility starts no later than 60 days after the publication of the implementation guidelines. This incentive is expected to accelerate the start-up of many projects still awaiting a final investment decision to benefit from these credits. Additional labour, prevailing wage and apprenticeship requirements must be met for projects starting construction after this date.

Alternatively, producers opting for the investment incentive may benefit from a subsidy of up to 30%, depending on their hydrogen lifecycle emissions. The IRA also includes investment incentives for renewable energy sources (30% until January 2025) or energy storage facilities installed before January 2025.

Finally, the IRA also covers carbon capture and storage (CCS) installations, which benefits many blue hydrogen or synthetic fuel production projects. Production subsidies of \$85/ton $CO_2$ captured and geologically sequestered, or \$130 to \$180 per ton CO2 obtained by direct air capture, are granted. However, the credit for low-emission hydrogen is not cumulative with carbon capture and storage incentives.

### 2.3.2 Carbon Contracts for Difference

As shown in section 2.1, the European Union has set itself the goal of becoming climate neutral by 2050. Hence, numerous efforts are being initiated to achieve this goal, with electrification and energy efficiency being the key focus areas for the energy transition. However, there are some sectors, such as the industry, where direct electrification faces numerous technical and economic constraints. In this context, low-emission hydrogen and $CO_2$ capture appear as the main, if not the only, existing alternatives[16] . However, although electrolysers and carbon

[15] Emissions reductions in comparison to the production of grey hydrogen (reforming of fossil natural gas)
[16] The efficiency of current CO2 capture processes is around 55 % and many studies put its maximum value at 90 %. This means that the only climate-neutral technology for the decarbonization of these sectors is green hydrogen.

capture facilities are already available on a commercial scale, they are still niche markets, and there is still a long way to go for their large-scale production and deployment. Rapid large-scale deployment of low-emission technologies is only possible if they are commercially available, achieving cost reductions and building the necessary infrastructure.

For this reason, public policies must support adopting these technologies, helping their commercial scale implementation level and overcoming cost barriers. Several policy tools are in place or under development to achieve this goal, for example, the EU taxonomy, the European Emissions Trading Scheme (ETS), the EU Innovation Fund or the Carbon Border Adjustment Mechanism[17] .

All these instruments stimulate least-cost emission reductions, giving priority to the cheapest abatement options. These signals stimulate the deployment of the most mature technologies but offer little attractive support for technologies in the demonstration phase. Investing in innovative technologies carries great risk due to uncertainty in future carbon prices which are difficult to predict due to political or technological changes.

Currently, no instrument allows market participants to hedge against these risks in the long term. This gap motivates carbon contracts for difference (CCfDs) as a regulatory instrument, which in conjunction with the EU ETS, can help deploy low-emission technologies[18].

A CCfD is a long-term contract in which a government and an agent receiving free allocations of emission allowances agree on a fixed strike price for carbon. Reducing its emissions, the agent sells free allocations it is not redeeming on the market. However, its return per allocation is contractually fixed with the government instead of subject to market price volatility. When the sale price is lower than the strike price agreed in the contract, the government pays the agent this difference. This type of contract is known as "put option" or "price floor". The contract can also be bilateral, meaning that the government will reward the agent if the price is lower than the agreed price. However, the agent will have to pay back the government when the reference price is higher than the contractual price, as illustrated in Figure 3.

[17] Proposal already submitted by the EC but pending on a vote by the European Council for final approval.
[18] CCfDs only work when there is a free allocation of emission allowances which means that companies will be able to sell in the market all the free allowances that they have not redeemed due to the use of low-emission technologies.

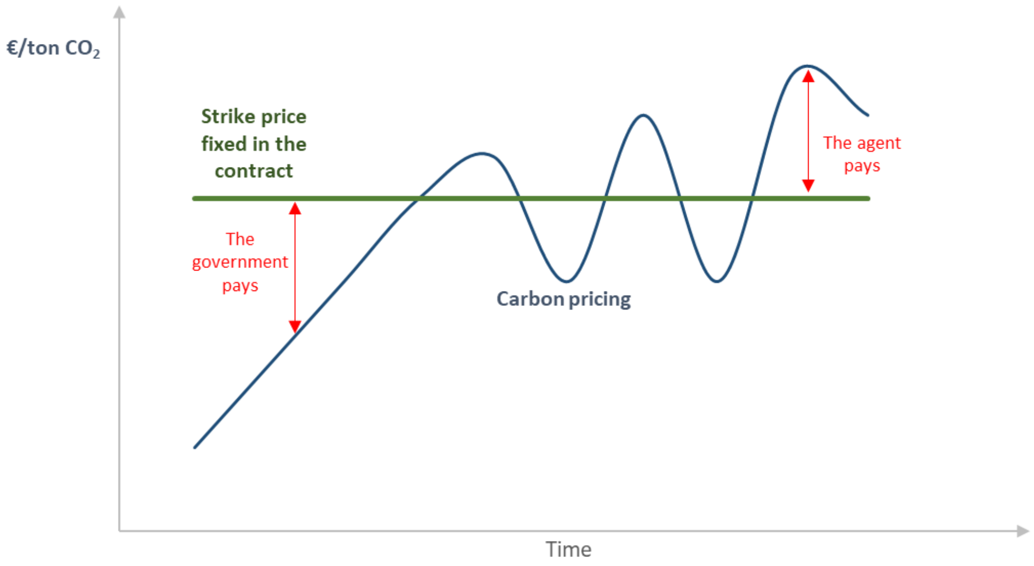



*Figure 3. CCFDs operation. Source: Economy for Energy Blog [3].*

**For example**, a steel production plant using a blast furnace (very polluting) may be interested in switching to a direct reduction technology (DRI) with green hydrogen. This technology change would require large investments that could be recovered to a certain extent by selling emission rights from the $CO_2$ emissions abated.

Assuming that the change of production to a low-emission technology has an additional cost of €150/ton steel and that the emissions avoided by the change of technology are 1.5 ton$CO_2$ /ton Steel; the price at which emission allowances should be sold to make this investment profitable is $\frac{150\ €/ton\ steel}{1{,}5\ ton\ CO2/\ ton\ steel}$ = 100 €/ton $CO_2$. This means the company could sign a CCfD with the government for a value of €100/ton $CO_2$ for ten years. When the carbon market price is lower, the government pays the steel plant the difference for each ton of carbon reduced; when the market price is higher, the steel plant pays the difference to the government.

In addition to CCfDs, there are other types of contracts for differences (CfDs), such as CfDs indexed to the price of energy[19] . In any form, CfDs can encourage a shift from existing technologies to cleaner technologies, including those based on green hydrogen. For this reason, many European governments are already working on such systems or considering their future application.

In this context, the most experienced country within the EU is the **Netherlands**, offering a subsidy similar to CCfDs under the SDE++ program. SDE++ extends a previous scheme intended exclusively for renewable energy projects. SDE++ includes technologies that can contribute to emission reductions, such as renewable heating, low-emission hydrogen production or carbon capture and storage. Projects compete in auctions for a contract under the SDE++ on the basis of the cost of emission reductions (€/ton CO2 abated), awarding the contract to the project with the lowest abatement cost. The technologies are grouped by emission factor ranges so that different technologies can compete on an equal basis.

[19] A detailed explanation of all types of CfDs and their characteristics are beyond the scope of this paper. For further information please refer to the report. [4]

In **Germany**, CCfDs were mentioned in the national hydrogen strategy. A special program for pilot projects is being developed by the Ministry of Economic Affairs and Climate Action. Many unanswered questions about the tendering process remain[20]. **Poland** also includes CCfDs in its national hydrogen strategy, although no information about concrete implementation plans is available. **France, Hungary, Sweden, Belgium** and **Spain** have also shown interest in implementing CCfDs to meet their climate targets and support the creation of a hydrogen economy.

Outside the EU, the UK Department for Business, Energy, and Industrial Strategy has published several reports evaluating CCfDs as an option for supporting CCS facilities and hydrogen production. The latest report advises a variable support system indexed to gas and hydrogen market prices [5]. Instead, the preferred option for carbon capture is a contractual design that reimburses the difference between operating costs and carbon market revenues.

According to BNEF data, the measures required to finance the production of 10Mt of renewable hydrogen, set as a target in REPowerEU, include the introduction of CCfD to support hydrogen uptake in the industry. REPowerEU itself is committed to this path by using the resources of the innovation fund to implement a Europe-wide CCfD scheme[21,] introducing subsidies of 100% of the cost difference between hydrogen and fossil fuels. Projects will be selected competitively to create a system of contracts by differences. However, these plans to increase funding to 100% must be compatible with EU ETS rules.

There is great interest throughout Europe in developing the CCfDs mechanism. However, except for the Netherlands, no concrete legislative proposals had been published by October 2022. In the Netherlands, the first CCfD-like contract has been awarded under the SDE++ program. The Porthos project, a carbon capture and storage project in the North Sea, is already under construction but will not be operational until the end of 2024.

### 2.3.3 Analysis and conclusions of the international context

The international context analysis is vital for comparing, planning, and correcting regulatory measures for the hydrogen sector. Successful measures elsewhere can be imitated, whereas measures that may reduce the competitiveness of the European continent at a global level can be discarded. This section, far from exhaustive, has analysed some of the most relevant policy initiatives.

Firstly, we looked at the role of hydrogen in the US IRA aid package, which has received much interest from the global hydrogen sector. Among the most highlighted elements by sector stakeholders, in contrast to the European and national level, are the amount of available funding and speed in granting aid, the simplicity of the eligibility rules, and technological neutrality. The uproar caused by the IRA in Europe shows a great general interest in developing hydrogen. Furthermore, it could cause a tractor effect for other countries to develop their own aid packages.

On the other hand, this measure generates greater competition to attract investment and develop a world-leading hydrogen sector. As was pointed out by the European Hydrogen Association (Hydrogen Europe) in a letter to the EC, concerns prevail about a possible exodus of

[20] A draft for the German CCfD scheme was published in December 2022. Two months after publishing the original version of this report.
[21] See Annex REPowerEU

investments from Europe to the United States due to simpler and more attractive conditions for the sector [6]. Even without definitive evidence, it is not unreasonable to say that the approval of this law and the fear of an investment exodus have influenced the European Parliament's decision to eliminate the additionality requirement for renewable hydrogen and substantially soften the time correlation requirement.

Finally, we would like to point out that both internationally and in the national context, hydrogen subsidies often seem to be directed mainly or exclusively to hydrogen production, leaving out potential off-takers. Reducing the costs and scale-up of renewable hydrogen production is highly relevant to make it competitive with traditional technologies. However, it is no less true that potential consumers have to make large investments to adapt their production processes in many cases. Even if renewable hydrogen is competitive in price, the technology change may take longer than desired, so there are not enough off-takers available to consume all hydrogen.

One of the many policy tools that address this gap is CCfDs, whose implementation is taking its first steps in Europe. It could become a key instrument to increase hydrogen demand in the short term, accelerate the energy transition, and give Europe a competitive advantage to attract investment. The first of these initiatives is the SDE++ in the Netherlands which allocates CCfDs by auction to those projects that can reduce emissions at a lower cost. Therefore, it is chosen solely based on the cost of emission reductions without considering other factors, such as its role as a demonstration project in a strategic sector. It would be important to consider all relevant factors, at least in the initial phase of CCfDs, to enable hydrogen development.

# 3. ANALYSIS OF HYDROGEN PROJECTS IN SPAIN

# 3 Analysis of hydrogen projects in Spain

## 3.1 Context and motivation

There are some databases and maps about hydrogen projects, such as the database published by the International Energy Agency [7], ENTSOG [8] or the Project pipeline of the European Hydrogen Alliance [9]. However, these tools are intended to cover a very large scale (global or European level), are not updated regularly and do not contain enough information to make a detailed analysis.

There is a large discrepancy between the number of projects in each database. For example, in the Spanish case, the map published by ENTSOG includes 28 hydrogen projects[22]; in the Pipeline Project, there are 337[23], and in the IEA database, the number of projects is 108[24] . For this reason, we decided to make our own map of projects. The map is updated periodically to provide an overview of planned or existing hydrogen production projects and show where the first hydrogen clusters or valleys could emerge.

This interactive map was created based on the best publicly available information, which has several important limitations. Therefore, the information may not be accurate for each and every project, but it does provide an overview of the overall status of the projects. This map is available on the Chair's website[25] (see Figure 4).

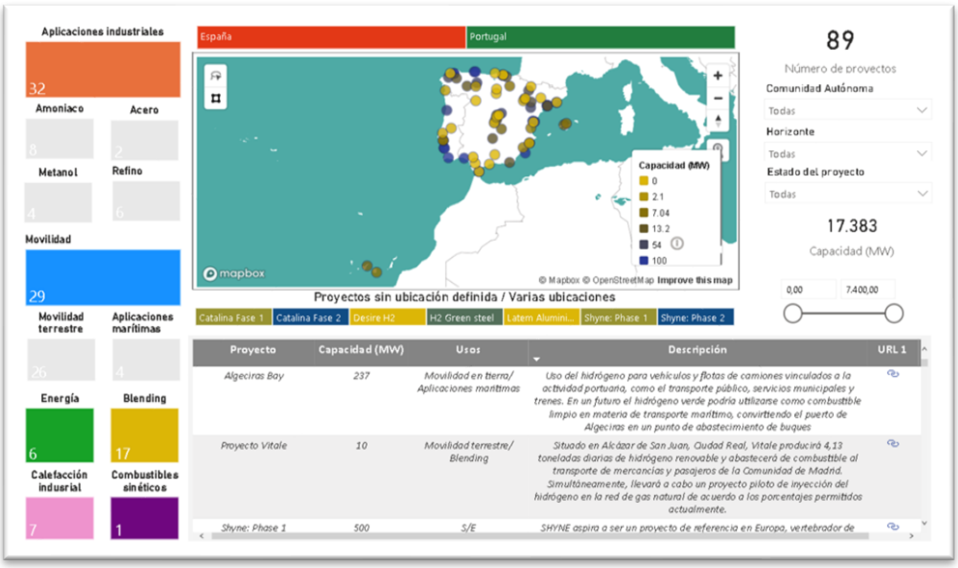



*Figure 4. Interactive project map*

This tool allows for analysing the status of hydrogen production and utilisation projects in the Iberian Peninsula, including (but not limited to) aspects such as the degree of progress of the

[22] The date of the last update is not specified; many important projects are yet to be included.
[23] The same project can count several times if it is intended for different applications which explains the large number of projects. In addition, many research projects are included.
[24] It is the most reliable database. However, it includes all projects already decommissioned as well as small pilot projects. It is only updated annually with the last update date being October 2022.
[25] [Chair for Low Carbon Hydrogen Studies (comillas.edu)](Chair for Low Carbon Hydrogen Studies (comillas.edu))

projects, technologies and mode of connection with renewable energies, types of off-takers or alignment with the objectives of the national roadmap.

## 3.2 Current status and ongoing projects

### 3.2.1 Project status

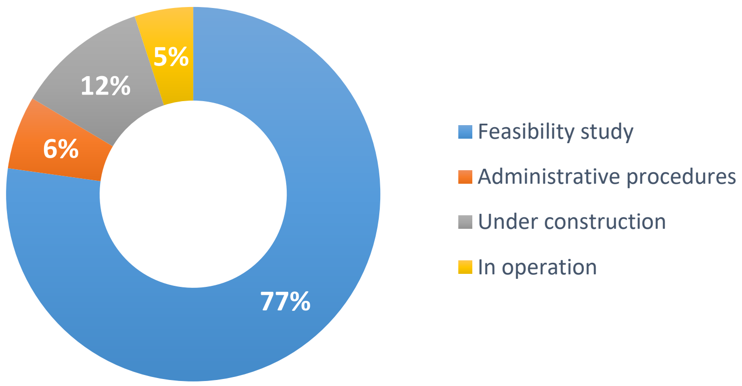



*Figure 5. Status of hydrogen projects*

At this report's publication date, 79 projects related to hydrogen production or consumption have been identified in Spain. Most (77%) of these projects are in the feasibility study stage[26]. In many cases, their approval is subject to the granted state aid under the NextGeneration framework. Of the remaining 23%, 18% is under construction or undergoing administrative procedures to initiate construction, and the other 5% (4 projects) corresponds to hydrogen projects that are already operational in Spain. Spain is one of the pioneering countries worldwide concerning the use of renewable hydrogen. Namely, these are Fertiberia-Iberdrola's green hydrogen production plant in Puerto Llano [10] and the PowerToGreen project in Mallorca [11], the hydrogen refuelling station for public buses in Barcelona [12], and the $H_2$-Login logistics project in Toledo [13].

### 3.2.2 Connection scheme

The electricity needed to produce the hydrogen by electrolysis can be obtained in two ways: with a direct connection to a renewable energy plant or through a grid connection point, typically subject to a PPA contract.

Although many projects do not specify where this electricity will be sourced from, the vast majority of those that do opt for the construction of a new renewable energy production plant, while only five projects opt solely for PPA contracts (see Figure 6). Such design decisions could have been affected by the time correlation and additionality criteria set by the now discarded Delegated Act on additionality (see section 2.1). Potentially many future projects would opt for the PPA model, although this will also depend on the requirements imposed by the various aid programs.

[26] It is assumed that projects are at the feasibility study stage if they have been announced, but no information about planned start of construction or the permitting process are available. Normally, no final investment decision has been taken at this stage.

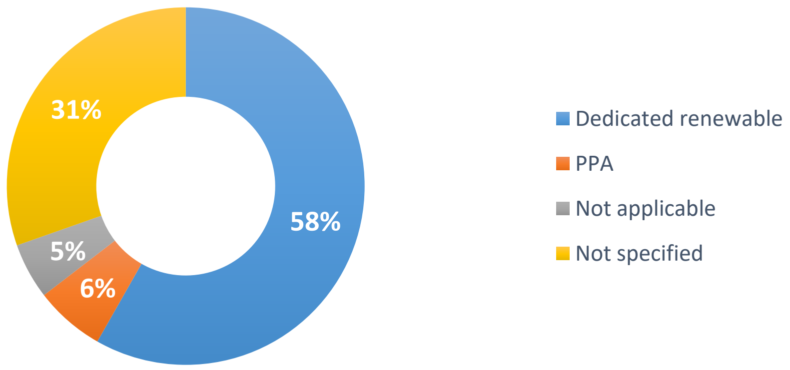



*Figure 6. Connection scheme of hydrogen projects*

Among the projects that include constructing a new renewable energy plant, most opt for photovoltaic energy (58 %) or hybridisation in combination with wind energy (14 %). Only 18% opt for wind energy alone, either onshore or offshore.

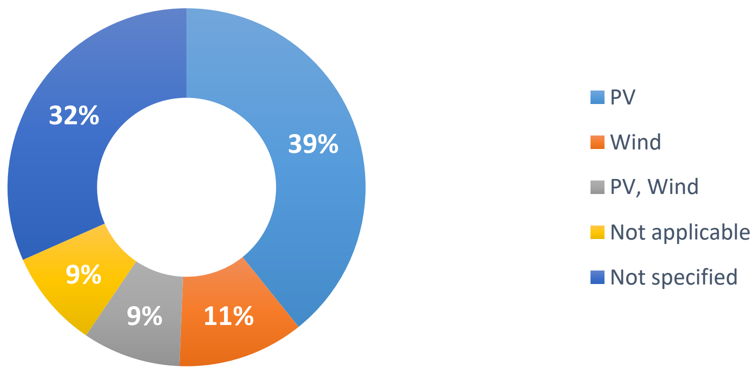



*Figure 7. Type of new construction dedicated renewable.*

### 3.2.3 Projects by sector

Due to the great versatility of hydrogen and the local character of its production and consumption, most projects are intended for more than one application, making it difficult to classify them. For this reason, it has been decided to count each application of the same project as an independent project. For example, a project may be destined for land mobility and industrial applications, which may count as a separate project in each sector.

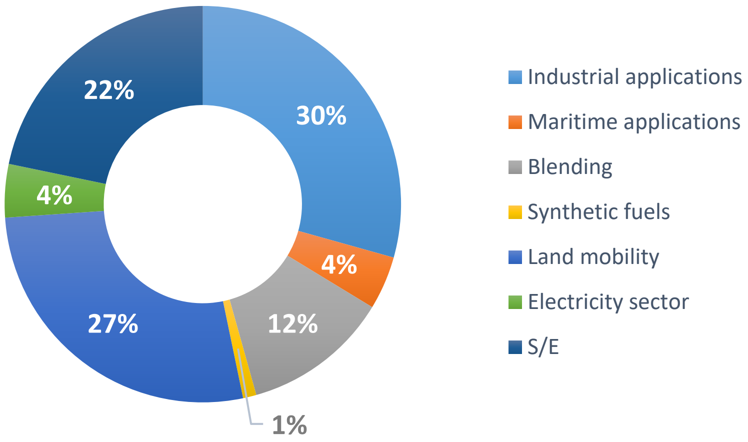



*Figure 8. Number of projects by sector*

Of the 79 projects included in this report, 20 do not specify in which sectors the hydrogen will be used. As expected, most are dedicated to industrial applications and land mobility, followed by hydrogen projects for injection into the natural gas grid[27]. Maritime applications, energy storage, and synthetic fuels are still in the early stages of development, and there are only a few projects in these sectors. For industrial applications, projects can be grouped into ammonia, refining, methanol and industrial heat production. (see Figure 9).

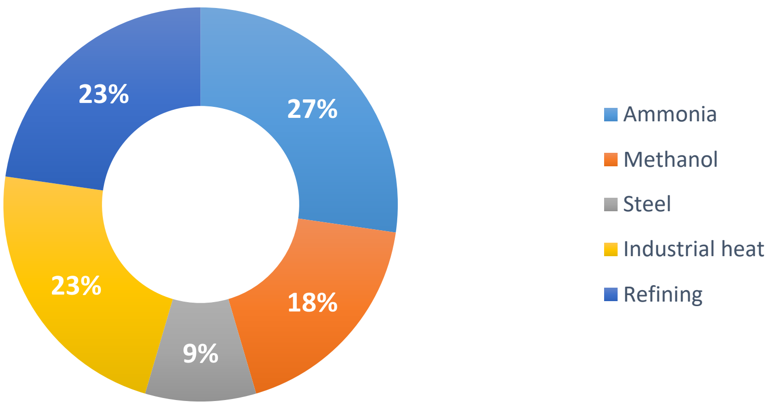



*Figure 9. Hydrogen projects by industrial subsectors*

Comparing the number of projects in Figure 9 suggests that, in the 2030-time horizon, both industry and terrestrial mobility will have similar importance. However, if we compare the projected MW capacity for each of these sectors (Figure 10), it is clear that industry-related projects will be the most relevant by 2030. The largest projects planned for 2030 are focused exclusively on the industrial sector: the HyDeal project (7.4 GW) [14], the Catalina project (2 GW)

[27] Current legislation allows 5% hydrogen blending, although the technical feasibility of injecting higher percentages is under investigation. The feasibility of the blending projects is subject to the approval of the guarantees of origin system which presumably will not be ready until 2023. The feasibility of injecting hydrogen into the natural gas grid is directly related to the transfer of GdOs that can be redeemed by consumers.

[15] or the $H_2$ Green Steel project (1 GW) [16]. Finally, there is a large amount of electrolysis capacity with unspecific end-use[28] .

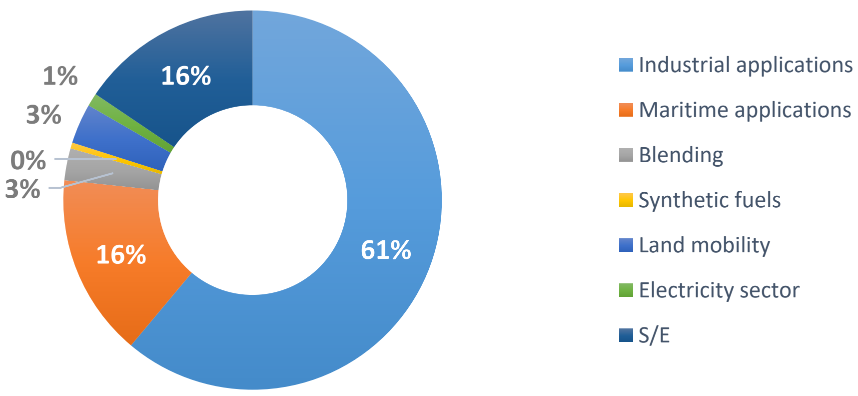
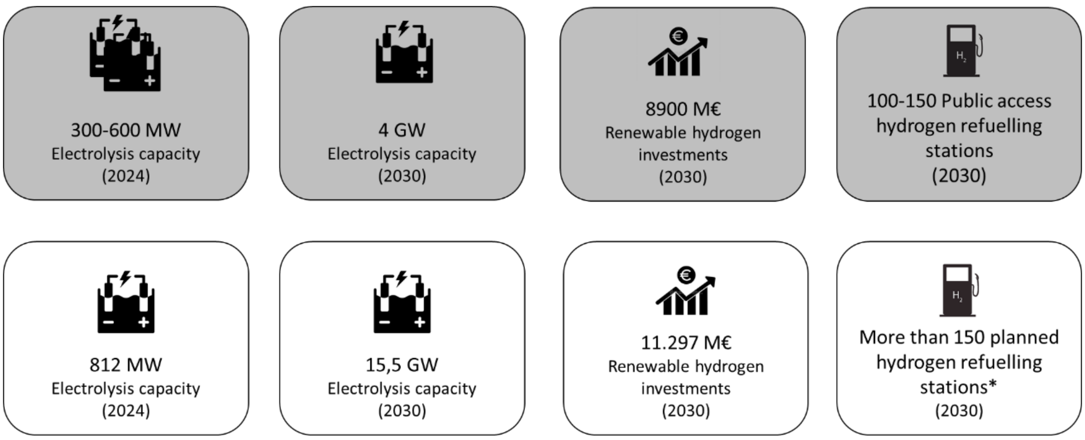


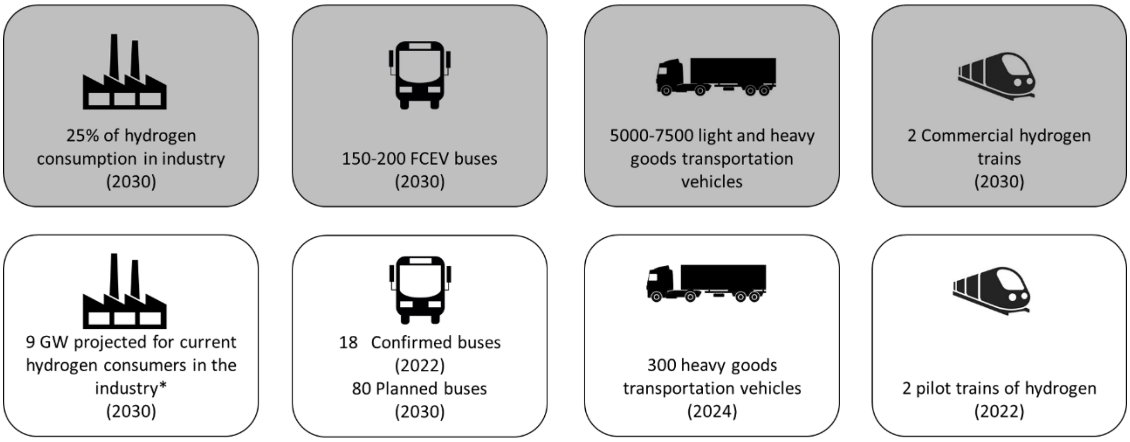

*Figure 10. Installed/projected electrolyser capacity (MW) by sector.*

## 3.3 Alignment with Roadmap objectives

The hydrogen roadmap for Spain, "Hoja de Ruta del Hidrógeno: una apuesta por el Hidrógeno Renovable" (Hydrogen Roadmap: a commitment to Renewable Hydrogen), sets several objectives for 2030. This section compares these targets with the projections obtained using our project observatory (Figure 11).




[28] A brief summary of the most relevant projects for each sector can be found in Annex 1.




* It is not specified how many will be of public access.
* It is impossible to compare the 25% of hydrogen to be consumed in the industry with current projects. A comparison with the projected electrolysis capacity for current hydrogen consumers (refining, fertilisers, and methanol) is included.

*Figure 11. Roadmap objectives (grey) and hydrogen project projections (white).*

The installed capacity forecast for 2024 (812 MW) exceeds the capacity set by the Roadmap for this date (300-600 MW). By 2030, the projected capacity (15.5 GW) will be approximately four times the capacity set by the roadmap (4 GW).

The planned investment is €11,297 million, exceeding the €8.9 billion target for 2030. Similarly, the number of HRS plants exceeds the targets, with more than 150 hydrogen refuelling stations (HRS) planned. Although it is not specified how many of them will be of public access.

Concerning buses, so far, 8 FCEV[29] buses have been confirmed for Barcelona [12] and 10 for Madrid [17]. Other projects also involve FCEV buses, including the HyVus project in Alicante [18]. The project proposes the construction of a hydrogen plant with a refuelling capacity for 80 fuel cell buses.

As for freight vehicles, the only project identified to date is the "Hydrogenizing Barcelona" Project, which involves 60 companies. The Project plans to deploy 20 MW of electrolysis power produced from the hybridisation of photovoltaic panels located on the roofs of the urban area of Barcelona and PPAs, as well as the necessary infrastructure to supply 300 trucks with hydrogen [19].

Also, two pilot projects are already underway to test hydrogen fuel cell technology in trains. One of them is developed by Iberdrola and CAF [20], and another by Repsol and Talgo [20]. Both are at an advanced stage, and although they are no commercial hydrogen trains yet, it seems feasible that the roadmap's objective will be met.

Finally, it is worth mentioning that the target for hydrogen consumption in the industrial sector is very difficult to quantify based on available information. By 2030, 25% of all hydrogen consumed at the industrial level should be green hydrogen. One way to approximate the likeliness of meeting this target is to look at the energy demand projected for current hydrogen consumers: refining, ammonia, and methanol. These sectors add up to a projected power of

[29] Fuel Cell Electric Vehicle

approximately 9 GW and a total of 15 projects: 5 refining projects (9 existing refineries in Spain), 6 projects related to fertiliser production (20 production plants registered with the National Association of Fertilizer Manufacturers), and 4 projects related to methanol. Based on these figures, we can be optimistic about meeting the roadmap's milestone.

## 3.4 Summary and critical analysis of national projects

It isn't easy to find reliable and up-to-date information on hydrogen projects. The large differences between the numbers stated for Spain in different databases of the IEA, ENTSO-G or the pipeline of projects of the European Clean Hydrogen Alliance are exemplary. Moreover, the information available for the different projects may be limited or outdated.

The lack of reliable information makes it difficult to analyse the state of hydrogen in Spain critically. For this reason, we have tried to fill this gap by collecting information on hydrogen projects underway that is as complete and updated as possible. We also make this information publicly available through our website. We believe this work can be very useful for various actors in supporting their decision-making process.

The gathered information allows us to observe some interesting trends concerning the milestones in the national Spanish hydrogen roadmap. The projected or declared electrolysis capacity for 2030 far exceeds the targets set in October 2020. Therefore, if we consider the collected data reliable, set targets will probably have to be revised to more ambitious ones in 2023. Even though the roadmap does not set targets for blending and barely mentions it throughout the document, many projects mention blending among their potential applications. Future revisions of the roadmap should give more importance to blending and propose clear regulatory measures for its viability and operation.

Most of the hydrogen-related energy demand in 2030 is projected for the industrial sector. In the first half of the decade, consumption will focus on current hydrogen consumers: fertilisers, methanol, and refining with some new small-scale applications such as hydrogen use for heat production. Only in the second half of the decade do we expect new hydrogen use cases in the industrial sector, such as the production of synthetic fuels and, above all, steel production, to become important.

There is also considerable interest in using hydrogen for transport, mainly in urban buses and, to a lesser extent, for freight fleets. In the case of the latter and unlike the transport sector, most transport vehicle fleets are privately owned. As a result, switching to hydrogen fuel cell vehicles is expected to be slower, requiring a minimum number of hydrogen refuelling stations to be made available beforehand.

We at the Chair believe the large number of projects and projected hydrogen capacities demonstrate the great interest in developing this sector at a national level and positioning Spain as a world leader in hydrogen production. However, the great majority of these projects are still in the preliminary stage, and it is worth asking how many will materialise with announced characteristics and meet announced deadlines.

The current situation is undoubtedly linked to prevailing uncertainty created by some of the regulatory measures proposed, revoked and implemented on the European and national levels, as discussed in section 2. We at the Chair believe that the process towards a hydrogen economy must be accompanied by a clear and simple policy framework to facilitate hydrogen deployment and provide investment security in the short term without losing sight of the long-term objective of decarbonisation. It is to be expected that the status of several projects will change very soon, given that the award of national aid programs is expected to take place in the month after the publication of this report[30]. Hence, an increasing number of projects will start to materialise. However, due to the lack of experience with hydrogen projects, we should not underestimate the technological uncertainties associated with the availability and performance of required equipment, which may affect the projects' implementation.

[30] The hydrogen support programs were provisionally solved in December 2022 (after the date of publication of this report). The provisional resolution is available on the electronic website of the Institute for Energy Diversification and Saving (IDAE). https://sede.idae.gob.es/lang/.

# 4. ANALYSIS OF HYDROGEN PROJECTS IN EUROPE: COMPARISON WITH THE EUROPEAN ROADMAP AND THE REPOWEREU INITIATIVE

# 4 Analysis of Hydrogen Projects in Europe: comparison with the European roadmap and the RePowerEU initiative

## 4.1 Analysis and comparison

The European Hydrogen Strategy (COM/2020/301) advocates that achieving the EU's energy transition would require large-scale hydrogen production and consumption. This transition must align with the European Green Deal, the New Industrial Strategy for Europe, and the Recovery Plan. In this document, the EU targets a minimum of 6GW of electrolyser capacity by 2024 and 40GW by 2030.

Targets were updated with the Fit for 55 package and the RepowerEU package launched in May 2022 to ensure European energy independence. The hydrogen accelerator, one of the medium-term measures of RePowerEU, highlights the need to increase electrolyser production capacity to meet the expected demand from the European industry. In this context, electrolyser manufacturers have specified an electrolyser production capacity target of 17.5 GW by 2025[31] . Moreover, the RePowerEU plan calls for the annual domestic production of 10Mt of renewable hydrogen, which represents an increase of 67% (4Mt) over the 6 Mt stated for Fit for 55. 8Mt of renewable hydrogen is expected to replace 27 billion cubic metres of natural gas by 2030. The remaining hydrogen will replace oil and coal. It is also proposed that annual renewable hydrogen consumption should reach 20Mt by 2030, of which Europe would import 10Mt.

Nonetheless, according to data provided by BloombergNEF, [1] based on the projects announced, the renewable hydrogen production capacity in Europe, the Middle East, and Africa (EMEA) at the end of the decade would be 3.3Mt. This projection is far from the 10Mt production target announced in the REPowerEU program. According to this data, the expected production would have to triple to achieve the proposed target. Hence, there is a strong need to promote and finance additional new green hydrogen projects. According to BloombergNEF's May 20202 estimates, there are not enough projects planned in Europe to meet this ambition. However, several countries intend to produce blue hydrogen to complement green hydrogen. The IEA estimates that hydrogen production from fossil fuels and planned CCUS projects in Europe will reach 3 Mt by 2030, mostly based in the Netherlands and the UK.

The latest IEA Global Hydrogen Review[33] provides a more optimistic forecast than the previous one, but it is still far from the target. It estimates that low-emission hydrogen production from water electrolysis could reach 5 Mt in Europe by 2030, with Germany and Spain jointly accounting for 1.4 Mt.

If we analyse the electrolysis capacity required to achieve the production targets, under the assumption of a conservative estimate in terms of operating hours and electrolyser

[31] See detailed information on medium term measures: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe_es
[33]https://iea.blob.core.windows.net/assets/c5bc75b1-9e4d-460d-9056-6e8e626a11c4/GlobalHydrogenReview2022.pdf

performance[34], it would be necessary to install around 17GW per year and in total approximately 140 GW to produce 10Mt by electrolysis until 2030. If we compare this figure with other estimates, there is a significant gap. The IEA's Global Hydrogen Review estimates that Europe will reach an electrolyser capacity of 39 GW by 2030, relatively close to the 44 GW target set in the Fit for 55 package. However, more ambition would be needed to reach the 65GW to 80 GW[35] of installed capacity proposed by REPowerEU[36] .

Finally, let's analyse the data of European projects included in the International Energy Agency (IEA) hydrogen project database. We estimate that these European projects would add up to an installed capacity of 176 GW, well above previous projections. It would also indicate that the planned projects would be sufficient to meet the targets proposed in the REPowerEU.

The divergence between different estimates may be partly because the IEA has recently reviewed their project database. It is also important to note that the definition of low-emission hydrogen and the current status of projects may differ between sources. The IEA definition includes hydrogen produced through electrolysis if the electricity is generated from a low-emission source (renewable or nuclear), biomass or fossil fuels with CCS/CCU. It is also important to note that 32% of the projects are at a very early stage of planning without a feasibility study. The remaining 68% are at a more advanced stage, of which only 4% are projects under construction or where the final investment decision has already been taken.

In summary, hydrogen production targets in the European Union have been revised upwards twice since the European strategy was published in 2020. It demonstrates the strong interest in developing a hydrogen economy in Europe, fuelled further by the ongoing energy crisis. However, forecasts of different institutions for domestic hydrogen production in Europe, which can be achieved by the end of the decade, do not allow us to be optimistic about the probability of achieving these ambitious targets. Likewise, when translating hydrogen production estimates into the installed capacity of electrolysers, it has become clear that the result is highly sensitive to the assumptions made, which is not always fully transparent in the revised reports. In fact, it is difficult to assess the likelihood of achieving set targets due to the high disparity in the estimates provided by the different sources, as seen in Figure 12.

[34] These calculations assume 4000h of electrolyzer operation per year and an efficiency of 55kWh/kgH2 (approx. 60%). The electrolysis efficiency would decrease with more equivalent hours of operation or higher yields.

[35] To produce the 10Mt of renewable hydrogen exclusively by electrolysis with an efficiency in the high range of current technology capacities of 70%, this would imply equivalent operating hours between 5800h and 7200h.

[36] See https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52022SC0230&from=EN

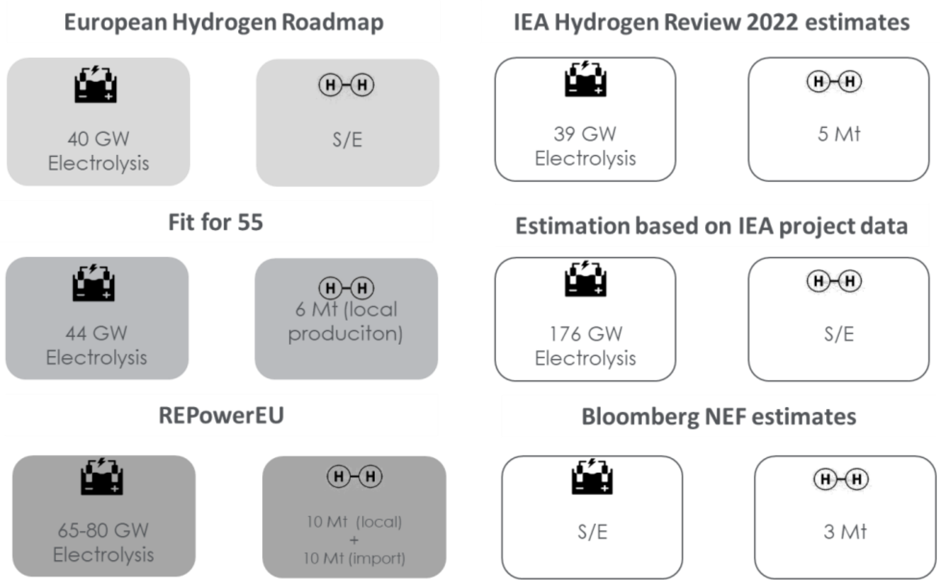



*Figure 12. Hydrogen production targets in Europe and predictions from different sources.*

## 4.2 Summary and critical analysis of European projects

Since the publication of the Hydrogen Strategy for Europe in July 2020, the European Union has twice revised its low-emission hydrogen production and consumption targets upwards, first with the Fit for 55 package in July 2021 and then again by RePowerEU in May 2022. It shows the growing importance that European authorities place on this energy carrier for decarbonisation and promoting the continent's energy independence and security.

RePowerEU mentioned above sets hydrogen utilisation targets of 20Mt by 2030, half of which would be produced within European borders and the other half supplied by imports. However, estimates provided by various institutions indicate that we will not be able to reach these production levels in Europe within the set timeframe, remaining between 3Mt and 5Mt in 2030. For this reason, the deployment of electrolysers needs to be accelerated or installed green hydrogen capacity needs to be complemented with other forms of low-emission hydrogen. For example, through carbon capture, as already stated by some European countries.

When translating these production targets into installed electrolyser capacity, we end up with various values differing per source. This divergence seems to be due to the different calculation assumptions considered for the performance, technological development and level of utilisation of electrolysers.

Similarly, if we consider different estimates (not those of the power necessary to meet the 2030 targets, but those of the projects that could materialise), we again find a great disparity in the numeric estimates. Figures range from those indicating that we are far from what we would need to those indicating that we will have plenty of capacity to spare. All show a strong increase in relevant projects over recent years or months. However, the most optimistic forecasts are often based on the inclusion of many projects still in the early development stage.

Hence, our analysis shows a need to improve monitoring precision and how we account for hydrogen production and utilisation projects, as well as greater transparency and homogenisation in the calculation hypotheses. Given this lack of reliable and robust information, it isn't easy to assess the degree of achievement of the targets set. As a result, it would be necessary to unify metrics at the European level to make decisions based on reliable data, as is currently being done by the Chair in the case of Spain.

# 5 Annex: additional information on hydrogen use by sector in Spain

**Hydrogen refining industry**

In 2020, the refining sector was the biggest consumer of grey hydrogen globally [21]. The substitution by green hydrogen would reduce the sector's emissions in the short and medium term. Spanish refineries are aware of the importance of hydrogen in this context. Out of the nine refineries currently operating in Spain, most are implementing or have green hydrogen projects planned.

Petronor's refinery in Bilbao has already installed a 2.5 MW electrolyser to produce green hydrogen, which shall be distributed to the Abanto Technology Park through a dedicated pipeline[22]. Although initially, the hydrogen produced will not be consumed at the refinery, there are plans to increase the installed capacity to 100 MW and use the hydrogen at the refinery.

The BP Castellon refinery is also betting heavily on hydrogen, with a projected capacity of 60 MW by 2023 and 95 MW by 2030 [23]. The project also serves as a driver for hydrogen in the region, with the ceramics industry as a future hydrogen consumer.

In line with the above proposals, the Tarragona and Cartagena refineries each project capacities of 100 MW green hydrogen [24], while Cepsa's refineries in Huelva and San Roque-Algeciras are planning green hydrogen projects with Endesa that are subject to European funding [25].

At the A Coruña and Puertollano refineries, no commercial-scale project for hydrogen production and consumption has been announced. However, in the latter case, a pilot plant-scale project plans to demonstrate photocatalysis technology [26]. It is a project funded by the EU Innovation Found program, and it will have a capacity of 100 kgH2/day to be consumed onside in the plant.

**Synthetic fuels**

Despite efforts to reduce emissions during their production, using fossil fuels for energy will always produce greenhouse gas emissions, which is incompatible with decarbonisation and climate neutrality in the long term. For this reason, a transformation towards more sustainable and non-polluting business models, such as biofuels or synthetic fuels based on hydrogen, is necessary.

In Spain, Petronor's refinery in Bilbao will be the first to produce synthetic fuels with an investment of €67 M and an electrolysis capacity of 60 MW [27]. Construction has already started and is expected to be completed by 2024, with 50 barrels per day production capacity. The Cartagena refinery is also investing in a similar approach but for producing biofuels from biomethane instead [28].

**Hydrogen for ammonia production**

After the refining industry, ammonia production for fertilisers was the second largest hydrogen-consuming sector in 2020 [21]. As in refining, currently consumed hydrogen is grey. Its replacement by green hydrogen is easier than in other sectors since it is not necessary to modify the other equipment used or the production process.

One of the most important operational projects to date and one of the most important worldwide is Iberdrola and Fertiberia's renewable hydrogen plant in Puertollano. This plant was inaugurated on May 13th 2022; it is the largest green hydrogen plant for industrial use in Europe, with a capacity of 20 MW of electrolyser and 100 MW of dedicated solar power [10].

It is not the only plant of this type planned by both companies. The alliance between Iberdrola and Fertiberia is also planning a green hydrogen plant in Palos de la Frontera with an electrolysis capacity of 210 MW by 2024 and 370 MW by 2027 [29].

In addition to those mentioned above, there are two other major ammonia projects. The Catalina Project aims to develop 2 GW of electrolysis, and it will connect Aragon and Valencia through a pipeline that will transport hydrogen to a newly built ammonia plant [15]. In addition, there is the HyDeal, one of the world's largest planned hydrogen projects. It will be located in Asturias with an electrolysis capacity of 7.4 GW by 2030, which will also supply hydrogen to Fertiberia's fertiliser plant in Avilés [14].

**Hydrogen for methanol production**

Five projects dedicated to green methanol production have been identified in Spain, two located in Galicia and three in Andalusia. The first Galician project is the Iberdrola-Foresa Green Methanol project with a capacity of 20 MW. In the first phase, the installation would allow for an annual production of 10,000 tons of green hydrogen, scalable to 200 MW and 100,000 tons/year [30]. The second one is Triskelon, an initiative that is a finalist for the European Commission's Innovation Fund and eligible for Next Generation funds. Its objective is to produce 40,000 tons of green methanol with an investment of 130 million euros [31].

In Andalusia, the company Viridi Energías Renovables España is promoting three projects related to methanol production. The first one, SolWinHy, is planned in Arcos de la Frontera (Cadiz). The project requires an investment of 210 million euros for a production capacity of 30,000 tons per year which is expected to be operational by 2025. After the construction of this first plant, two other plants are planned in Cordoba, with a production capacity of 30,800 tons per year and in Linares, with a production capacity of 44,000 tons per year [32].

These initiatives total 284,800 tons of methanol. To put this figure into perspective, in 2020, approximately 932,000 tons of methanol were consumed in Spain [33].

**Hydrogen for steel production**

The primary steel industry is one of the most polluting sectors, as the energy and heat needed to convert iron ore into steel comes mainly from coal. Switching from coal to green hydrogen is key to the sector's transformation and represents a great opportunity to reduce the high emissions associated with this process.

Steel production plants are characterised by their very large size, which translates into very high projected electrolyser capacities. The first steel-related project in Spain is promoted by the Swedish company H2 Green Steel and Iberdrola [16]. The site is yet to be decided. It will require an estimated investment of €2.3 billion, with construction scheduled to begin between 2025-2026. The new plant would have a capacity of 1 GW of green hydrogen, using it as a clean fuel in a direct reduction furnace with a capacity of 2 million tons per year of green steel with a 95%

reduction in CO2 emissions. To put these figures in perspective, 14.1 million tons of steel were produced in Spain in 2021 [34].

Another steel-related project is HyDeal [14], mentioned above in the context of ammonia production. With a projected capacity of 7.4 GW by 2030, much of the hydrogen produced is expected to be used for steel production at ArcelorMittal's plants in Avilés and Gijón.

**Hydrogen thermal uses**

Concerning the thermal use of hydrogen, most domestic projects involve the ceramics sector, a sector with a very important industrial weight in Spain. Two relevant projects are worth mentioning: Orange Bat [35] and GreenH2ker [36]. The first one foresees the construction of a 100 MW plant with an investment of 100 million euros which will be operational by 2025. It will be located in the area of Castellón, an area that concentrates 95% of the Spanish ceramic industry. The GreenH2ker project is also located in Castellón, a project between Iberdrola and Porcelanosa to decarbonise the ceramics industry by developing a coupled system including green hydrogen production and consumption and a heat pump to be implemented within the kiln at the Porcelanosa factory in Villareal.

Another project for the thermal use of hydrogen is that of Latem Aluminium [37] for two green hydrogen production plants in Castilla y León. The first would be located at Latem Aluminium's factory in Villadangos del Páramo, and the other at its plant in Villabrázaro (Zamora). The project would allow for renewable energy self-consumption for the aluminium manufacturing process in these factories.

Finally, Coreses (Castilla y León) is scheduled to host one of the largest green hydrogen plants in Spain, with a production capacity of 300,000 tons per year and an investment of €400 M [38]. The plant is expected to be completed by the end of 2025. It will be used to replace the natural gas consumed by local industry and inject part of it into the natural gas grid.

**Hydrogen in transport**

Hydrogen projects related to road transport mainly focus on establishing hydrogen refuelling station networks for heavy vehicles.

The two most ambitious projects are Desire H2 [39] and Win4H2 [40]. Air Liquide and Redexis intend to create a network of 100 HRS in Spain by 2030, whereas Naturgy plans to build a network of 38 HRS by 2025, expandable to 120 in the second phase (Figure 13).


*Figure 13. Map of the hydrogen refuelling stations network. The first corridor is highlighted in orange. Source: Naturgy*

In addition to those mentioned above, Iberdrola is planning a network of hydrogen refuelling stations in Alicante, Valencia, Zaragoza, and Barcelona. The last one is already in operation and supplies 8 buses used for public transport. It also provides hydrogen to the private company Evarm, which specialises in transforming vehicles with combustion engines into sustainable vehicles.

Barcelona is not the only city that bets on hydrogen. In Madrid, there already is a line of public buses running on hydrogen in Torrejón de Ardoz. The purchase of additional 10 buses and the construction of a green hydrogen production plant in the Entrevías operations centre of the public transport company EMT have also been announced. In Alicante, the HyVus project [18], with a budget of €10 M, plans to start a hydrogen refuelling station that can supply up to 80 hydrogen buses operated by transport provider Vectalia. Other cities such as Tarragona, Canarias, Zaragoza or Valladolid are considering including hydrogen buses in their fleet.

**Hydrogen in the electricity sector**

The use of hydrogen in the electricity sector mainly targets hybrid applications for combined cycle power plants in combination with natural gas. In the case of the Amorebieta-Boroa combined cycle power plant, 1,500 tons of green hydrogen shall be consumed per year. Grid electricity to operate the electrolyser will be contracted via PPAs [41]. The project will require an initial investment of 50 million euros. The plant with an electrolysis capacity of 20 MW shall be in operation by the end of 2022. Its expansión to 200 MW capacity before 2030 is subject to a total investment of 300 million euros.

On a smaller scale, there are two projects where hydrogen is used for energy storage. The first one is the Digital H2 Green Malaga Project. Artificial intelligence will control energy generation, storage, and supply operations. The second project is the Sustainable Mobility Hub in Toledo [42] which is already under construction. Besides a hydrogen plant, a storage module consisting of a battery and hydrogen-fuel cell storage system will be installed.

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# CHAIR FOR LOW CARBON HYDROGEN STUDIES
# 2021-2022

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