European Commission

ENTEC

Energy Transition Expertise Centre

Terms of Reference

The role of H2 import & storage to scale up the deployment of renewable H2

Terms of Reference – Hydrogen Import and Storage

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Content

1 Background and objectives

The **European Commission's hydrogen strategy** presented in July last year outlines, amongst other elements, how to upscale the demand and supply of renewable hydrogen. It has set the strategic objective to install at least **40 GW of renewable hydrogen electrolysers within the EU** and the production of up to **10 million tonnes of renewable hydrogen** in the EU.

To reach these targets, a substantial amount of additional **renewable electricity** (~500 TWh) will be needed to produce renewable hydrogen (on top of the large amounts of renewable electricity that will be needed to electrify applications that are currently served by other energy carriers) and to achieve 55% CO2-emission reduction by 2030.

The characteristics of renewable capacities, such as its seasonal variability, the time needed to realize (additional) solar and wind parks to produce renewable hydrogen, as well as potentially low public acceptance for the development of (additional) renewable production sites requires us to have an in-depth look into the **role of renewable hydrogen import (infrastructure)** as well as into the **role of hydrogen storage (infrastructure)** to decarbonize the European economy.

2 Research questions

At the moment it is not clear whether domestic production of H2 will achieve the strategic EU 2030 goal of 40 GW installed electrolyser capacity and whether demand for H2 can be met in 2030. Thus, the **domestic production and import** volumes are not clear.

- What is the expected domestic production in 2030 based on current plans and project developments? Is this sufficient to meet the EU 2030 goal (40 GW)?
- Is there a gap between expected domestic demand for H2 and its carriers in 2030 and beyond (2050) in the EU and how does this match with the production capacities?
- What is more cost-efficient – imports of H2 or increase of domestic production capacity (in case of a gap between expected domestic production and demand) in 2030 and beyond? This entails an outline of competitive advantages (production outside vs inside EU)
- What are the likely imports of H2 and its carriers in 2030 and beyond? And which are countries that will most likely export to the EU?

There exist many scenarios about the future energy mix and demand in the EU including imports of H2 and its carriers[1], but less information and assessment are available on infrastructure needs, especially regarding H2-carrier-specific **transport modes**.

- Which transport modes are needed and suited for the different types of H2 carriers and the expected imports?
- What role could non-network-based transport modes e.g. LNG terminals play for H2 imports?
- What role could network-based transport modes (outside the EU) such as existing pipelines for natural gas play in light of natural gas supply security?
- What are cost-efficient transport modes for H2/H2 carriers imports?

In view of variable RE electricity generation and seasonal variations, the questions of **storage** and its economic value and impact on the energy system arise.

- What storage options do exist (potentials, costs, etc.) for different types of H2 and its carriers across the EU?
- Which revenues can storage generate in this system? Are there non-captured revenue streams?
- Does the use of storage options reduce the required electrolyser capacities for a secure base-load supply of industries?
- What is the impact of storage options on the electricity system? Does an increase in storage affect flexibility, and hence electricity prices? Or does it substitute other sources of supply security
- What kind of asset is storage? What are the risks (classes) and what are the resulting cost of capital?
- What are potential regulatory needs to incentivize the development of hydrogen storage locations?

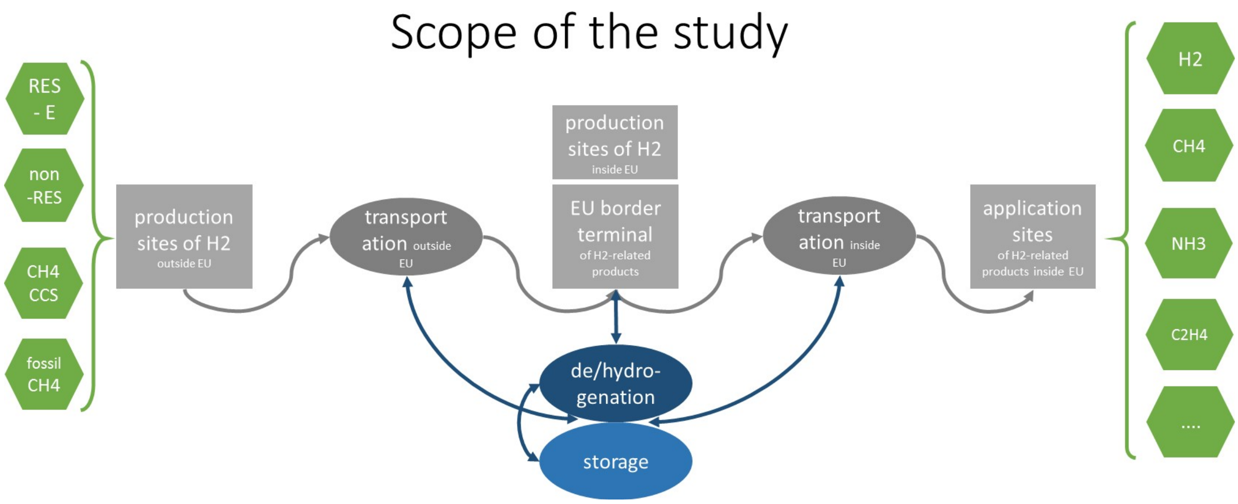
[1] *H2-carriers* refer to the way how hydrogen is transported. This could be in 1. gaseous or 2. liquid form (LH-2) or 3. bound/converted into other molecules such as LOHC or Ammonia. H2-derivative refers to the (end)product that is derived from H2. H2 is being 'processed' further into a fuel/feedstock

3 Tasks and approach

In a first step we define the scope of the study. The scope is described along the H2 value chain. This value chain is disassembled into modules (or components). Each module can take different characteristic values (forms/levels/features/options). We have defined the following modules and its characteristic values:

- Production by origin of H2 e.g. methane-based with and without CCS, electricity-based with and without renewables (100%)
- Transformation of H2 in/from derivatives (or carriers), e.g. liquid and gaseous hydrogen, methane, ethanol, ammonium, ethylene, etc.
- Transportation across border e.g. network, non-network for different types of H2 and H2-carriers
- Storage and flexibility options by type of H2 and H2-carriers e.g. gaseous H2 in salt or rock cavern, liquid storage in, by type H2, tanks, etc.
- Application by type of H2 derivatives (or carriers), e.g. liquid and gaseous hydrogen, methane, ethanol, ammonium, ethylene

For the scope of the analysis we agree with the EC which modules and characteristic values will be included in this study. Regarding the origin and derivatives of H2 we suggest to include them all if possible while the geographic coverage and productions sites will be results of the tasks. The different modules are depicted in the following figure.



For the analysis we suggest, first, to analyse the different modules separately, i.e. we describe and analyse the different characteristic values of the modules. To assess from a systemic perspective, we then select different combinations of characteristic values and, assembly a value chain (production, transformation, transportation, storage), and assess and compare their combined financial and system impacts.

3.1 Task 1: Framework, scenario selection and outlook

In task 1 we set the framework of the analysis. We identify the scenarios of energy supply and consumption up to 2050 for the EU, limit the geographical coverage of the transportation infrastructure as well as define the origins and derivatives of H2 that are part of this analysis. A (key) starting point is to fill the gap of % Mton to meet the 10 Mton of H2 in the EU's H2 strategy, (and use MIX-55-40 GW scenario if possible).

As output we get a limited set of scenarios that are the basis for the further analyses carried out in tasks 2-4.

Prior to the actual selection of the scenarios, a literature review is performed to get an overview of existing sources and relevant European energy scenarios. This analysis is also used to identify potential gaps in analyses or information of existing scenarios. These gaps might be filled using additional sources or EnTEC internal knowledge.

The framework and scenario selection will be agreed in consultation with the EC.

Approach:

Desk research/Literature review

- Existing sources/scenarios/studies at EU level e.g. [2]
    - EU Impact assessment (2020), rework of the scenario in 2021 (PRIMES)
    - Towards net-zero emissions (JRC 2020)
    - Pathways to deep decarbonisation of industry (EC 2019)
    - A clean planet for all (EC 2018)
    - Scenarios of the potential of RFNBOs and RCFs over the period 2020 to 2050 in the EU transport sector and beyond
- Scenarios at national levels:
    - German Federal Ministry long-term scenario (ISI, 2021); Climate neutral Germany (Agora 2020)
    - *National low carbon strategy SNBC (The French Ministry for the Ecological and Solidary Transition, 2020)*

Exchange with and input from the EC:

- Projection study on transport modes/gas infrastructure (e.g. retrofitting plan of existing gas infrastructure)
- Data on H2 demand by type of H2 carrier and supply by type of H2 origin (blue, green, …)

Workshop with EnTEC and EC to derive "final" scenario

For reasons of consistency and comparability we suggest to base the work mainly on the reworked impact assessment scenario (with PRIMES & other models) including the H2 strategy ambitions.

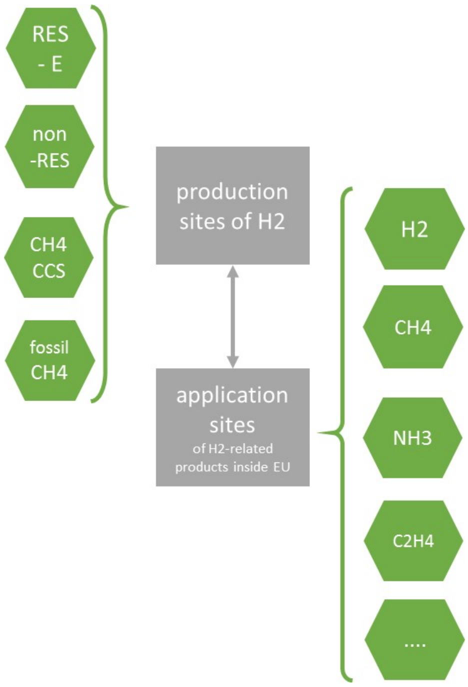
[2] Contributions of partners: Gas for Climate (Link), Net-Zero Europe (Link)

3.1.1 Output Task 1

- Overview of H2 supply within the EU and from abroad by type of H2 origin and demand for H2 and its carriers
- Gaps in existing studies/analyses
- Framework of the analysis

3.2 Task 2: The role of H2 imports in the EU by 2030

Under the assumption that the strategies and policies of MS and the EU would not add up to the strategic goal of 40 GW of installed electrolyser capacity (current national hydrogen strategies add up to approximately 27 GW) or that H2 demand in 2030 cannot be met autonomously, more insight in the import of renewable hydrogen is needed. Therefore, we compare current and future domestic production capacities by types of H2 origin and look into types of H2 carrier, if possible (see the following figure) and applications. The potential gap could be covered by upscaling domestic production or imports. As we look at different time horizons, we apply two type of sources for this comparison: current plans and projects and scenarios for future developments up to 2050.



3.2.1 Production and transformation technology

To derive the potential imports we look at recent and future applications and productions within the EU and outside the EU.

To depict the current and near-future situation following data are collected:

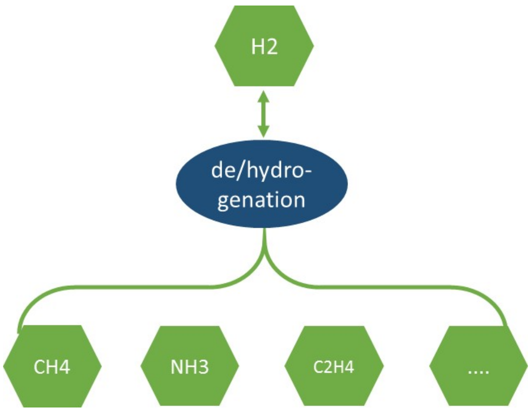
- Current production in EU and outside by origin of H2
- Planned production: projects and plans of electrolyser in EU and outside by origin of H2

With respect to productions and applications till 2050 we use the scenario defined in Task 1 and use the following data:

- Demand in EU by type of H2 carrier or derivate or by application?
- Supply in EU by origin of H2 (see H2 strategy of EU)
- Supply outside EU by origin of H2
- Future H2 exporting countries

Given these data, we can assess the potential gap of H2 between domestic supply and demand. We align this gap to the different types of H2 carriers based on the domestic demand structure. Thus, we identify to what extend H2 should be imported (shipped) into the EU and in which form it could be transformed (as liquefied hydrogen, ammonia and/or LOHC[3], etc.)

In a next step we collect information on and assess production costs (electrolyse) by origin of H2 and geographic location including the costs of transformation of H2 into H2 carriers as well.



The description and assessment of different production and transformation options include technical characteristics such as efficiency aspects, financial aspects such as upfront investments and operational costs, financing costs as well as potential barriers. The operational costs are strongly triggered by the geographic location (e.g. by RE potential, water, waste, risks) and prices for electricity and natural gas, while financing costs depend on the country's rating. The country risk is taken into account when comparing the competitiveness of different production locations.

Approach: Desk research, literature review (e.g. Global PtX Atlas), expert talks, techno-economic assessment.

3.2.2 Regulatory needs

Uncertainties due to unclear market and financing situations or disadvantages or distortions due to existing network regulation and energy policies will be assessed, with a special focus on the EU, along with policy and regulatory recommendations to address these barriers. Potential barriers and

[3] liquid organic hydrogen carriers

recommendations regarding standards for operational and environmental safety may be identified but is not a focus of the task.

Approach: Desk research on market uncertainties and interactions of existing policies.

3.2.3 Output Task 2

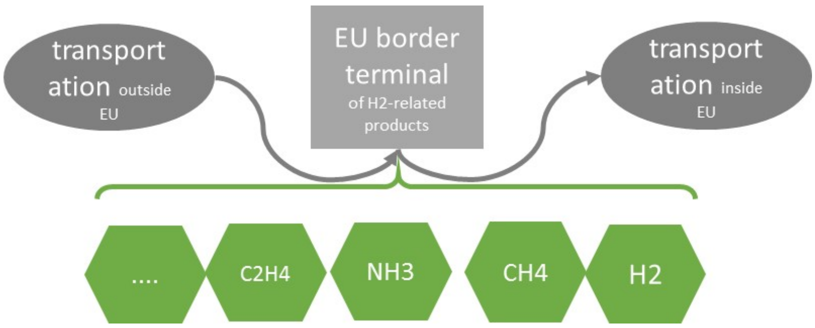
Outcome:

- list of potential exporting countries that reveals competitive advantages of of hydrogen production regions outside the EU vis-à-vis hydrogen production inside the EU
- gap between domestic supply and demand for H2 and derivatives
- overview of production and transformation technologies,
- technology- and site-specific H2 / H2 carrier production costs -> competitiveness
- Regulations ensuring safety (production), policies addressing barriers such as production and market uncertainties.

3.3 Task 3: Analysis hydrogen transport infrastructure by 2030

3.3.1 Technology overview

The transport modes depend on the types of H2 carriers, which in turn are determined by the competitiveness of production sites. Independently from the cost assessments in Task 2 we do evaluate the different transport modes for by types of H2 between the producing country outside the EU till the border of the EU. Within the EU, we rely on information of the EC's projection study on transport infrastructure.



In a first step we compare the identified gaps in Task 2 – ideally by H2 carriers – and compare it with the existing transportation modes. That is, we look at the non-network-based transport modes including (adapted) LNG terminals and put together information on current and expected specific transportation costs and capacities. Second, we look into the existing network and discuss to what degrees these networks could be used for H2/carriers transportation without endangering the natural gas supply security of the EU. We also investigate whether there are expansion/reduction plans of the exiting network and to what degree would that affect H2/derivates transportation. We collect and compare the costs of these different transport modes by type of H2/carrier.
As output we describe the transport modes by H2/carrier, including technical features, losses, specific costs, potential transport volume, expected developments (plans) with respect to network capacities and terminals as well as some geopolitical aspects and potential barriers. Further we highlight the potential contribution of existing pipelines and their limits.

Approach: Desk research, literature review (e.g. Global PtX Atlas), expert talks, techno-economic assessment.

3.3.2 Regulatory needs for infrastructure development

The focus of the analysis will be on policy and regulatory barriers and potential solutions for the development of H2 infrastructure between the EU and third countries (including potential issues at the interconnection points with third countries as well as networks beyond EU borders). In addition to eventual network regulation measures to facilitate the development or repurposing of pipelines, policy measures such as financial and non-financial incentives, strategic partnerships and transparency measures will also be considered.

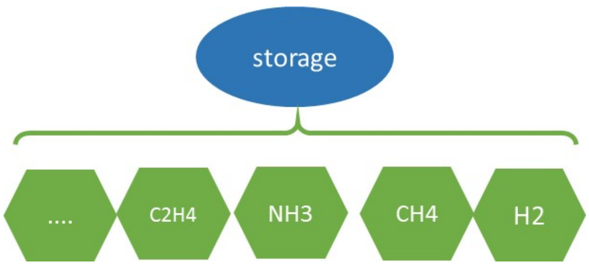
Approach: literature research and comparison with existing challenges of pipelines, their ownership structures, regulations and policies.

3.3.3 Output Task 3

- Quantity imported by type of carrier and transport mode i.e. to what extend H2 should be imported (shipped) into the EU and in which form (as liquefied hydrogen, ammonia and/or LOHC[4], etc.), or/and via pipelines through third countries (to the EU)
- Extent to which these carriers might be reconverted for subsequent injection into existing methane pipelines
- Overview on main features and costs of different transportation modes
- Potential role and development of existing network outside the EU
- Incentives and regulations to ensure competition and market entry

3.4 Task 4: Importance of hydrogen storage facilities in the EU

3.4.1 Technology Overview



In view of variable RE electricity generation and seasonal variations against a need for stable hydrogen supply by future users such as industry, the questions of **storage** and its economic value and impact on the energy system arise. In this Task we describe the different storage options – their potentials (capacity) and costs, for the different types of H2 and its carriers across the EU.

In a first step, we identify different storage technology options across the EU (existing, planned potentials) for H2 and its derivatives. In a next step we consider the potential contribution of storage to the system. Thereby we differentiate between the different contributions of storage for the energy and industry sectors:

The storage option provides a reliable supply of H2/derivative for industry and makes it partially or fully independent from variations in H2 supply strongly driven by variable RE electricity generation. This has in return implications for the capacity sizing of electrolysers as the capacity back-up becomes redundant. Thus, storage options reduce electrolyser needs to serve baseload demand, hence improving their economic viability.

In the energy sector, storage of H2 provides a flexibility source to buffer the short-term variable RE electricity generation. But it also represents a supply security option for seasonal fluctuations of RE generation or dunkelflaute moments. Finally, it could replace natural gas storages for providing seasonal flexibility needed due to winter heating demand. Storage also may improve the business

[4] liquid organic hydrogen carriers

case of electrolysers by allowing them to make use of low electricity price moments to produce hydrogen which is then stored. Depending on its usage, it may reduce the volatility of electricity prices, as well as their level (seasonal). We also investigate whether there are further revenue or non-monetary benefits.

These different applications of storages open the window for different business concepts. In the electricity sector H2-storage options compete with other flexibility resources, e.g. batteries, dispatchable generation or demand-side response, line-pack offered by over-dimensioned pipes, all of which may participate in capacity remuneration mechanisms e.g. capacity markets. Their usage depends on their competitiveness and technical characteristics. Given the different applications of storages, we derive a risk and asset classification, and assess the resulting costs of capital.

Further aspects of storages such as locations (e.g. close to import terminal, production or end-use points) and availability, size (small, distributed vs large, centralised), and type of storages (technical aspects such as pressure and permeability, withdrawal rates) are described.

Approach:

- Outline H2-storage options and their flexibility potential (technical aspects, costs)
- Identify applications for H2/derivatives and their demand profile
- Identify H2/derivatives supply options and their profile
- Define representative case studies combining supply (domestic and imported H2), storage and demand options covering the most important future hydrogen systems
- Define flexibility needs for each case study
- Define alternative flexibility sources and supply security mechanism for each case
- Compare flexibility contribution of H2-storage options vs other flexibility options, and associated costs & benefits – including technical and economic viability of electrolysers
- Compare costs and benefits of supply security options (including H2 storage)

3.4.2 Regulatory needs to incentivize the development of hydrogen storage locations

Storage options present a business opportunity. We consider different business approaches such as commercial contracting and outline the preconditions under which this business could be profitable. We describe potential barriers and drivers that could be addressed by selected policy instruments.

Depending on the storage scale, availability of geological sites and whether existing methane gas storage to be converted is regulated or not, some H2 storage may be regulated, while end-user and small-scale storage will not. Regulated and competitive regimes may affect the WACC and thus the business case of storage. If existing underground gas storages are the best candidates for future H2 storages, regulatory uncertainty on the regulatory regime and e.g. eventual compensation for current operators could constitute a barrier.

An incipient hydrogen market may not be liquid enough for users to be responsible for managing their imbalances, requiring the network operator to take the main balancing responsibility. Storage operators would in this case not contract storage capacity with end-users but directly with network operators (or if storage is regulated, operators could manage storage themselves), at least until a liquid market developed.

Issues with standards/regulations to guarantee environmental and operational safety may also be identified, but this is not a focus of the task.

Approach:

- Literature analysis and expert talks (industries);
- Barrier identification:
    - Technological
    - Permitting
    - Market
    - Financial
- Solutions
    - Regulated regime
    - Capacity mechanisms
    - Network operator responsible for defining and contracting flexibility needs
    - Market formation measures
    - R&I support
    - Network tariff discounts
    - Avoiding double taxation (at storage and end-consumption moments)
- Sensitivity analysis

3.4.3 Output Task 4

- Overview on storage option per technology and H2/derivative, including technical and financial information (technology-specific fact sheets) and main purpose of storage
- Storage potential (technical, economical/market) in the EU by storage options
- Contribution of storage to the system in terms of flexibility, supply security and economic value and economic viability of electrolysers
- Asset and risk classifications per storage option
- Regulations and policies addressing failures and barriers to storage

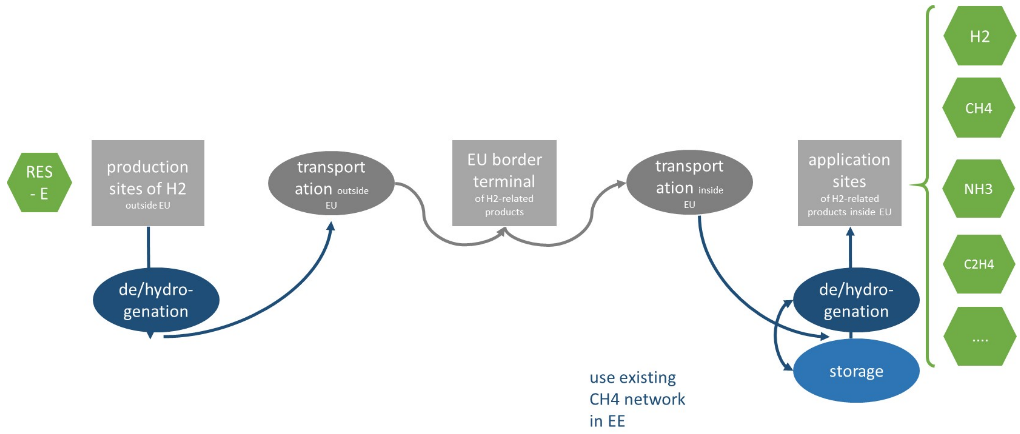
3.5 Task 5: Prospective analysis 'domestic' vs. 'external' H2 production

In this Task we combine specific characteristic values of the value chain and link it to the scenario (link to Task 1) to analyse the competitive advantages of H2 production outside the EU vis-a-vis a hydrogen production inside the EU.

Based on the results of Task 1 (gap volume), we combine selected

- production and transformation options and their costs (Task 2) that take into account location specific conditions
- modes of transportation of imported H2 and its derivatives, and the respective costs (Task 3)
- And eventually include storage option costs and benefits (Task 4)

We potentially include the upscaling potential of these options. A potential combination is depicted in the following figure.



Approach: Combination of results stemming from Task 1-4.

3.5.1 Output Task 5

- Assessment (no modelling) of the competitive advantages of internal vs. external H2 production
- Several partial scenarios with different types of H2/origins and production and transformation (and storage) options within the EU
- Several partial scenarios with different types of H2/origins and production and transformation and transportation options to the EU

4 Deliverables and reporting

For the purpose of this specific study, the following deliverables will be produced:

Deliverable Nr.	Title/ Short description	Type	Month	Lead
D1	**Task 1: Framework/Scenario Selection**	PPT	Mid of Mai 2021	Fraunhofer ISI
D2	**Task 2: H2 Import – Intermediate results**	Dataset + PPT	End of June 2021	Fraunhofer IEE
D3	**Task 3: H2 Transport – Intermediate results**	Dataset + PPT	End of June 2021	Fraunhofer IEE
D4	**Task 4: H2 Storage – Intermediate results**	Dataset + PPT	End of June 2021	Trinomics
D5	**Task 5: Analysis**	Dataset + PPT	Mid of September 2021 (tentative)	Trinomics
D6	**Final Report**	Report	Early October 2021 (tentative)	Trinomics + inputs from all partners/tasks

The deadlines for D5 and D6 were made under the assumption of a 2-week feedback period by the Commission after delivery of D1 to D4.

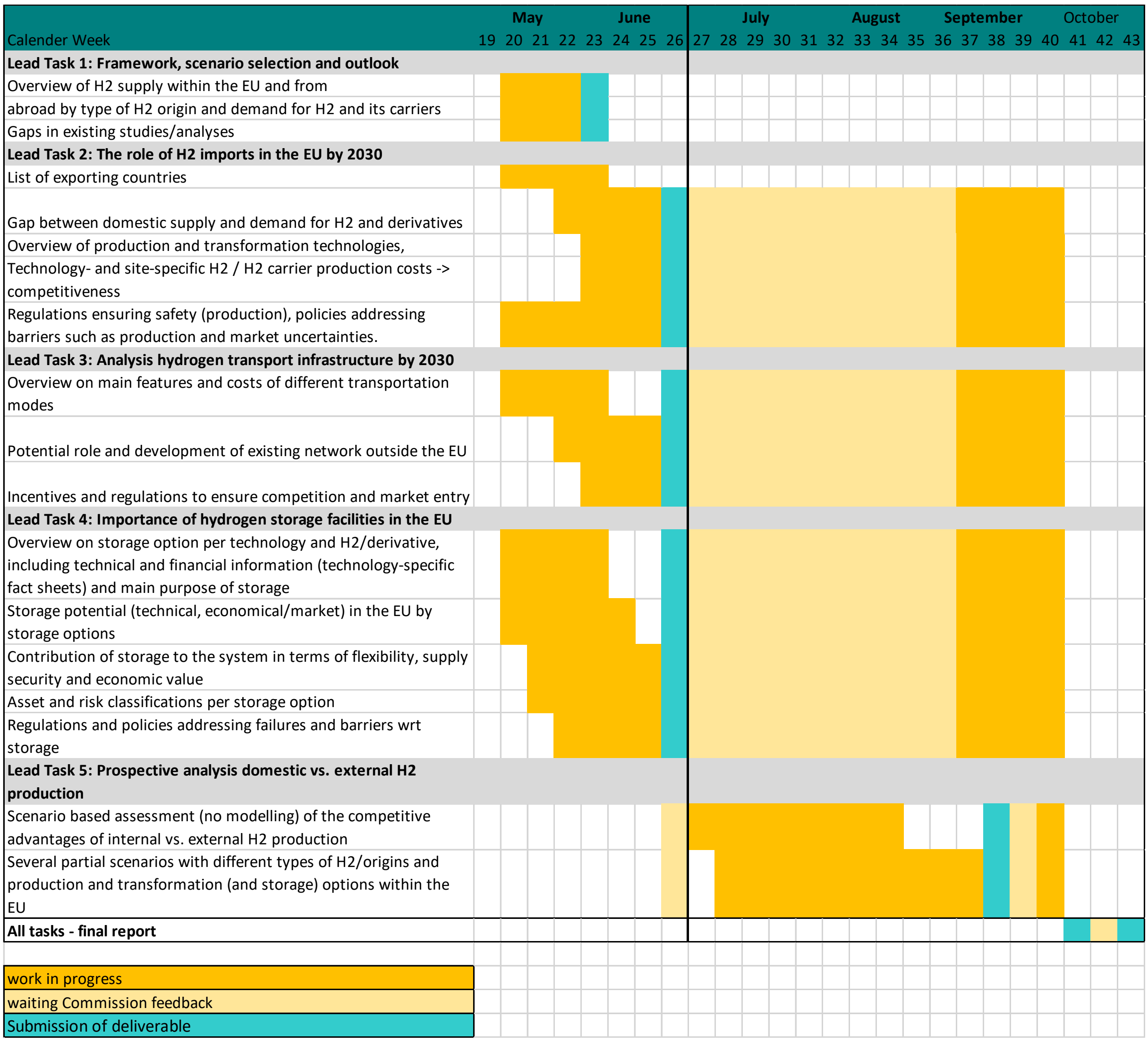
5 Work organisation

5.1 Resources

The following table shows the planned resources by task:

Task\Resource	Resource needs in days	Share of total resources in percent
Project Management/Meetings/Reporting	24	10%
Task 1: Framework, scenario selection and outlook	22	9%
Task 2: The role of H2 imports in the EU by 2030	32	13%
Task 3: Analysis hydrogen transport infrastructure by 2030	32	13%
Task 4: Importance of hydrogen storage facilities in the EU	80	33%
Task 5: Prospective analysis domestic vs. external H2 production	50	21%
SUM	**240**	**100%**

5.2 Work plan and timeline



As reminder, the Impact Assessment of the Hydrogen and Gas market decarbonisation package has to be delivered on 20 July.

The project teams suggest the following on-line meetings.

Meetings	Proposed date	Description
Kick-off meeting: 1st project phase (until June)	19th Mai 2021	Setting the framework for Task 2-4, discussion/coor-dination
Bi-weekly progress meetings	2/6, 16/6, 30/6	Progress report by task, discussion of open points
Interim project meeting	Possibly (and if required) early July 2021	Presentation and discus-sion of interim results
Kick-off meeting: 2nd project phase	To be decided later (end of Aug, or early Sept)	Setting the framework for Task 5 and final reporting
Final Meeting	To be decided later (mid-Oc-tober 2021 as tentative)	Final presentation of pro-ject results

5.3 Work distribution

Task	Lead	Contributors
Study Lead	Trinomics	
Task 1	Fraunhofer ISI	TNO, Trinomics, Fraunhofer IEE
Task 2	Fraunhofer IEE	Trinomics
Task 3	Fraunhofer IEE	Trinomics
Task 4	Trinomics	TNO
Task 5	Trinomics	TNO, Fraunhofer IEE & ISI

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