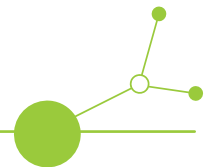




D.2.4.1

Business models' list

Report



Final version

01.2026





INVOLVED PARTNERS

Number	Organisation	Country
1	Landshut University of Applied Sciences	Deutschland (DE)
2	Mazovia Energy Agency	Polska (PL)
3	Regional Development Agency of South Bohemia - RERA	Česko (CZ)
4	Energieinstitut an der Johannes Kepler Universität Linz	Österreich (AT)
5	University of Zagreb Faculty of Electrical Engineering and Computin	Hrvatska (HR)
6	Energy Institute Hrvoje Požar	Hrvatska (HR)
7	HyFuture GmbH	Deutschland (DE)
8	Energy Agency of Savinjska, Šaleška and Koroška Region	Slovenija (SI)
9	South-Transdanubian Regional Innovation Agency	Magyarország (HU)
10	Deggendorf Institute of Technology	Deutschland (DE)
11	WeEurope Srl SB	Italia (IT)



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1. Context of the HYEFRE Project

1.1. Project description

HyEfRe brings together 11 partners from 8 Central European countries (Slovenia, Italy, Germany, Poland, Czech Republic, Austria, Hungary, Croatia). Their aim is to facilitate and support municipalities, cities, energy or regional planners and SMEs in the field of renewable energy in Central Europe to implement efficient, affordable, and sustainable energy systems through hydrogen integration and establishment of hydrogen ecosystems on local and transnational level.

HyEfRe will foster an investment-friendly environment for renewable energy and green hydrogentechnologies integration regarding energy efficiency (e.g. waste heat utilisation) and balancing, via an innovative holistic approach. Partners will evaluate hydrogen potentials with a new model and develop and test a new tool to calculate ideal parameters for technical plants. Their action plan for policy actors will reduce regulatory barriers impeding a timely expansion of renewables and green hydrogen.

Programme and project specific objectives:

HyEfRe project was approved within the “Cooperating for a greener central Europe” priority thematic, and the specific objective SO2.1: “Supporting the energy transition to a climate-neutral central Europe”.

In this frame, as stated before, the specific objective of HyEfRe is to facilitate and support the implementation of efficient, affordable, and sustainable energy systems through hydrogen integration and establishment of hydrogen ecosystems on local and transnational level.

1.2. HyEfRe work packages

The work on the HyEfRe project is divided up on to following work packages:

- **WP1** - Support for hydrogen project and energy planning: WP1 will enable 5 regions in CE in planning and decision making of green hydrogen projects and make learning results and tools publicly available.
- **WP2** - Social, regulatory, and economic framework: Wp2 will Support public authorities to improve social, regulatory, and economic frameworks for green hydrogen implementation and provide business models for industry stakeholders.
- **WP3** - Set up of a hydrogen ecosystem network: WP3 will Initiate the establishment of 8 hydrogen ecosystems in 8 CE countries to anchor tools and strategies and to provide implementation guidance, creating a network for joint actions.

The activities of each work package are carried on contemporary, i.e. different activities from work package 1 and 2 can be developed in the same project period/semester.



The HyEfRe project was approved under the call for proposals of the Interreg Central Europe Programme, within the multiannual financial framework from 2021 to 2027. It started in June 2024 and will end in November 2026.

1.3. Project outputs and result overview

The HyEfRe project will outline 3 results, which are marked as a solution under the programme result indicator RI 2.1: Solutions taken up or up scaled by organizations, Joint strategies and action plans taken up by organisations, and Organisations cooperating across borders after project completion.

The project results are summarised below:

- **Result 1:** the uptake of tool/model solutions (O.1.2, O.1.3) will lead to stakeholders' ability to develop economically and technically sound business models through digital-supported processing of data required. These currently non-used data will foster the RE/hydrogen integration into the energy system, supporting the transition to a carbon-neutral central Europe. The uptake of O3.3 will lead to governments' ability to establish hydrogen ecosystems, building on existing activities, improving stakeholder exchange, and making use of good practices created during this and other related projects.
- **Result 2:** the uptake of the project's strategies and action plans will result in the establishment of a friendly environment for investments into RE and hydrogen technologies. This will be achieved through fostering three main components: Action plan for policy framework improvements in the hydrogen economy (O.2.1) - Strategy for social acceptance increase for hydrogen applications (O.2.2) - Strategy for establishing hydrogen ecosystems (O.2.3). The uptake of the strategies will be ensured through associated partners who have already expressed their intent in using the learnings and recommendations, as well as by other public authorities.
- **Result 3:** the 11 project partners and 21 ASPs will cooperate beyond project duration with the goal of developing and implementing events, (scientific) courses and trainings, making use of the developed outputs. Furthermore, joint follow-up projects will be elaborated to further support the energy transition to a climate-neutral central Europe via RE and hydrogen integration, waste heat utilisation, increasing energy efficiency and sector coupling.



2. Objectives of the report

The primary objective of this report is to **support the development of Business Models (BMs) for hydrogen implementation, with a particular focus on guaranteeing the economic feasibility of hydrogen hubs** in Central European (CE) countries.

This document fulfils a critical translational role by converting the results of previous economic and financial assessments into concrete and replicable business model configurations. By identifying **viable implementation pathways**, the report assists decision-makers, public authorities, and market operators in navigating the emerging hydrogen economy. It provides a **practical framework to guide pilot actions** and future investments, thereby directly contributing to the **scalability and long-term sustainability** of hydrogen solutions.

In alignment with the broader HyEfRe project objectives, the report seeks to facilitate the implementation of **efficient, affordable, and sustainable hydrogen ecosystems** on both local and transnational levels. It supports the creation of an **investment-friendly environment** and provides industrial stakeholders with the necessary tools to **bridge the gap between innovation and commercialisation**. To achieve these goals, the document is structured to:

- Classify and examine specific business cases through an **analytical matrix** to identify and shortlist dominant strategic pathways.
- Perform a detailed **SWOT analysis** for selected models to evaluate their internal and external conditions, identifying specific **barriers to adoption** and delineating strategies to overcome these challenges.
- Establish a **stepwise roadmap for implementation** that integrates standard Business Plan elements with **cross-cutting analytical components**—including Cost-Benefit Analysis (CBA), Multi-Criteria Analysis (MCA), and Life Cycle Assessment (LCA)—to ensure project choices are technically sound and socio-economically justified.

Ultimately, the report serves as a strategic guide for transitioning **from isolated pilots to integrated regional ecosystems**, ensuring that hydrogen deployment becomes a robust and enduring component of **regional transformation strategies**.



3. Methodology

The document was developed using a multi-step methodological approach, designed to establish a solid conceptual foundation and translate analytical results into practical implementation plans.

1. Introduction to Business Model and state of the art of hydrogen implementation

The process began with a review of commonly used Business Model (BM) definitions, with the aim of establishing a solid and shared conceptual baseline. The analysis addressed the fundamental question: *what does a Business Model mean in the context of hydrogen hubs and which Business Models are most relevant to consider?*

2. Cases review and analytical matrix

To answer this question, specific Business Model cases were examined. Their distinguishing features were analysed and positioned within an analytical matrix structured around key variables:

- Initiative drivers: demand-side driven, supply-side driven, or territorial/place-based initiatives.
- End use / application: transport, district heating, industrial use or other applications.
- Financing model: public, private, hybrid.
- Energy source for production.

The matrix enabled a structured categorisation of different Business Models list, highlighting their specific characteristics and supporting the identification of a shortlist of illustrative cases. Business Models have been selected using the **Triple Layered Business Model Canvas (TLBMC)**. This framework ensures that each model is evaluated not only for its economic viability but also for its lifecycle environmental impacts and social value.

3. Identification and SWOT analysis

Subsequently, a **SWOT analysis** was carried out for the identified Business Model options in order to assess their strengths, weaknesses, opportunities, and threats.

4. Roadmap for implementation

Finally, the document developed a **roadmap** outlining the key steps required for implementation. The roadmap is primarily anchored in the structure of a standard Business Plan (BP) and is complemented by cross-cutting analytical components—such as **Cost-Benefit Analysis (CBA)**, **Multi-Criteria Analysis (MCA)**, **Life Cycle Assessment (LCA)**—to support decision-making and to identify the most suitable options in terms of overall benefits (economic, social, and environmental).



4. Introduction to Business Model for Hydrogen Hub

A Business Model (BM) describes the logic through which an organisation - or, in the case of hydrogen hubs, a coordinated ecosystem of actors - creates, delivers and captures value along the hydrogen value chain. It links strategic objectives with operational processes, financial flows and governance mechanisms in a consistent and replicable way, providing the foundation for bankable and scalable hydrogen projects.

In hydrogen hubs, the BM does not refer to a single asset but to an integrated, place-based system where production, infrastructure and end uses are co-located and interconnected within a defined territorial perimeter (e.g. ports, industrial clusters, metropolitan areas, inland valleys).

The BM for a hydrogen hub builds on standard components (later operationalised through an adapted Business Model Canvas and other templates in the annexes):

- *Value proposition:* products and services offered (renewable/low-carbon hydrogen, derivatives, flexibility and balancing services, logistics, certification of origin) and the specific added value for customers and stakeholders (decarbonisation, security of supply, regulatory compliance, cost optimisation).
- *Customer segments and relationships:* target segments (hard-to-abate industries, captive fleets, logistics operators, utilities, municipalities and regional authorities) and engagement models (long-term contracts, framework agreements, “as-a-service” solutions, joint ventures).
- *Channels:* delivery channels for hydrogen and related services (dedicated or repurposed pipelines, regional distribution networks, hydrogen refuelling stations and corridors, on-site supply for industrial clusters).
- *Key activities:* core activities such as project development and permitting, design and operation of production assets, infrastructure planning and operation, offtake structuring, system integration and balancing, stakeholder engagement and risk management.
- *Key resources:* physical assets (electrolysers, storage systems, compressors, pipelines, refuelling infrastructure), human capital and technical competences, digital tools and models (including design and sizing tools), as well as access to capital and institutional relationships.
- *Key partners:* renewable energy producers, TSOs/DSOs and gas network operators, industrial users, OEMs, ports and municipalities, regional energy agencies, financial institutions, energy communities and cooperatives that contribute critical capabilities, assets or legitimacy.
- *Revenue streams:* revenues from hydrogen and derivatives sales, network and storage tariffs, flexibility and ancillary services, green premiums for low-carbon products, service fees within infrastructure-as-a-service schemes and, where applicable, public support contracts.
- *Cost structure:* main cost drivers including CAPEX and OPEX for production and infrastructure, grid connection and land use costs, permitting and compliance, financing costs and risk management costs.



A hydrogen hub is an integrated, place-based ecosystem within a clearly defined spatial boundary where hydrogen production, storage, distribution and consumption assets are co-located and technically and contractually interconnected. The BM defines roles and interfaces between actors and specifies how investments, risks and benefits are allocated across the ecosystem. Typical actors include:

- Renewable energy producers supplying electricity to electrolyzers or other low-carbon production routes;
- Hydrogen production operators (electrolysis, reforming with or without CCS, emerging routes);
- Infrastructure owners and operators for storage, compression, transport and distribution;
- Offtakers in industry (refineries, steel, chemicals) and mobility (buses, trucks, rail, port operations, logistics fleets);
- Enabling institutions (port authorities, municipalities, regional agencies, regulators) that provide strategic orientation, regulatory alignment and, in many cases, financial support.

The hub BM focuses on coordination mechanisms - governance structures, long-term contracts, market interfaces and regulatory instruments - which make joint investments viable and ensure operational coherence over time.

Evidence from implemented and planned projects shows that there is no single “optimal” model; hydrogen hubs typically combine several configurations, and the mix evolves across project phases (pilot, scale-up, full commercial operation). Four archetypes are particularly relevant:

1. Infrastructure-as-a-service models

- Dedicated infrastructure entities (SPVs, regulated operators) finance, build and operate pipelines, storage and refuelling infrastructure.
- Users pay usage fees or capacity-based tariffs rather than owning the assets, reducing their upfront CAPEX and transferring part of the asset risk to the infrastructure operator.

2. Long-term offtake agreement models

- Producers and offtakers sign long-term contracts specifying minimum volumes, pricing formulas and indexation mechanisms.
- These agreements stabilise cash flows, de-risk demand and are essential for securing debt and equity, especially in industrial decarbonisation anchor projects and captive fleet applications.

3. Merchant or spot market models

- Hydrogen is sold without binding long-term commitments, with prices and clients chosen transaction by transaction in more mature or liberalised markets.
- This increases operational flexibility and potential upside but exposes projects to higher demand and price volatility and typically appears at later stages of market development.

4. Public-Private Partnership (PPP) and hybrid funding models



- Public authorities and private partners share investments, risks and responsibilities for key assets, especially in early stages when risks and uncertainties are highest.
- Hybrid funding combines grants, guarantees and concessional finance with private capital and, in some cases, community-based investment, underpinning most early-stage hubs and corridors in Central Europe.

Beyond standard BM blocks, hydrogen hub models must integrate three hub-specific dimensions that are developed analytically in the later chapters (matrix, SWOT, roadmap and annexed tools).

a). Policy and Regulatory Framework

- Encompasses strategic targets, enabling policies, support schemes (grants, contracts for difference, tax incentives, guarantees), network and tariff regulation, and certification rules for renewable and low-carbon hydrogen.
- Determines the investment environment and directly influences bankability, choice of production route, connection options and contracting structures.

b). Sustainability and Territorial Impact

- Covers environmental performance (GHG emission reductions, local environmental footprint) and socio-economic impacts (jobs, skills, SME involvement, just transition).
- Feeds into ESG reporting and sustainability KPIs and is later quantified through Life Cycle Assessment (LCA), Cost-Benefit Analysis (CBA) and other tools in the roadmap.

c). Risk and Resilience Management

- Addresses technological, market, regulatory, financial and supply-chain risks along the value chain.
- Uses mitigation instruments such as long-term contracts, guarantees, portfolio diversification, modular investment strategies and formalised risk assessment methods (Risk-Impact matrices, HAZID, HAZOP).

These three dimensions ensure that the BM is not only economically viable but also compliant, socially acceptable and resilient to shocks and structural changes over the project lifetime.

This chapter provides the conceptual backbone that is operationalised in the subsequent parts of the report:

- The matrix of business cases classifies real projects according to initiative driver (demand-side, supply-side, territorial/place-based), end-use application, financing model (public, private, hybrid/PPP) and energy source for production, making explicit how different archetypes combine in practice.
- The SWOT analyses translate the BM dimensions into structured sets of strengths, weaknesses, opportunities and threats, directly linked to barriers to adoption and mitigation strategies in Central European contexts.
- The implementation roadmap integrates the BM in a stepwise process that includes:



- strategic design tools (stakeholder mapping, RACI matrix, job-to-be-done, customer personas, value proposition and adapted BM canvases);
- techno-economic and environmental appraisal tools (DST outputs, CBA, MCA, LCA);
- risk and safety tools (Risk-Impact template, HAZID and HAZOP).

Together, these elements allow project developers and public authorities to move from conceptual Business Models to actionable, evidence-based implementation plans, supporting the transition from isolated pilots to integrated regional hydrogen ecosystems.



5. State of the art of hydrogen implementation: opportunities and challenges

Hydrogen is the lightest gas in the universe. Although it is not a primary energy source, such as coal or gas, is an energy carrier (similar to electricity) that can store and deliver energy in a widely usable form.

Moreover, hydrogen has an important role to play in decarbonising hard-to-abate sectors such as industry and heavy-duty transport, including maritime and aviation. It's worth of note some inputs gained from interviews, carried out in A1.1 of this project:

- LP: “The unused potential for production in Bavaria alone is 450,000 tonnes/year of hydrogen (25% of the consumption forecasts for 2030) with a GHG reduction of 5.8 Mto/year (8% of total emissions in the Free State)”¹;
- PP3: “It is also important to realize that if the green transformation of the energy sector continues at the current pace, particularly with the construction of solar and wind sources, we will find ourselves in a situation within a few years where it will be necessary to address what to do with surplus electricity. Green hydrogen could be one of the ways to store energy”²;

At the same time, imports of renewable hydrogen will need to be rationally planned and the development of a dedicated infrastructure carefully orchestrated. The production of hydrogen is at the start of the synthesis of any decarbonised gas and synthetic fuels. A successful energy transition cannot rely solely on the expansion of renewable electricity but must instead be based on an integrated approach that leverages all available potentials. In this context, renewable hydrogen plays a central role—particularly in hard-to-electrify industrial sectors—but its production must also be considered from a systemic efficiency perspective. Despite existing efficiency measures and technological advances, this form of energy generation is inherently linked to the process.

5.1. Overview of hydrogen technologies and their application

Hydrogen technologies are a key instrument to achieve the decarbonisation goals of the Green Deal and are at the core of the European Hydrogen Strategy and RePower EU Plan. Europe aims at producing and importing up to 20 million tons of renewable hydrogen (10 million tons of imports and 10 million tons produced in Europe) by 2030. This objective presupposes a remarkable growth in the deployment of hydrogen technologies across sectors and the development of a dedicated European infrastructure for hydrogen production, storage and transport across European territory.

According to JRC, since hydrogen is a fundamental building block for all renewable fuels and gases of non-biological origin, it's recommended to monitor innovation and EU industry competitiveness through the

¹ See HyEfre Partnership (2024) D.1.1.1 Report on Best Practices Assessment. rep. P. 9

² See HyEfre Partnership (2024) D.1.1.1 Report on Best Practices Assessment. rep. P. 31



assessment of hydrogen-related technologies across the full hydrogen value chain (production, transport, storage and final use).

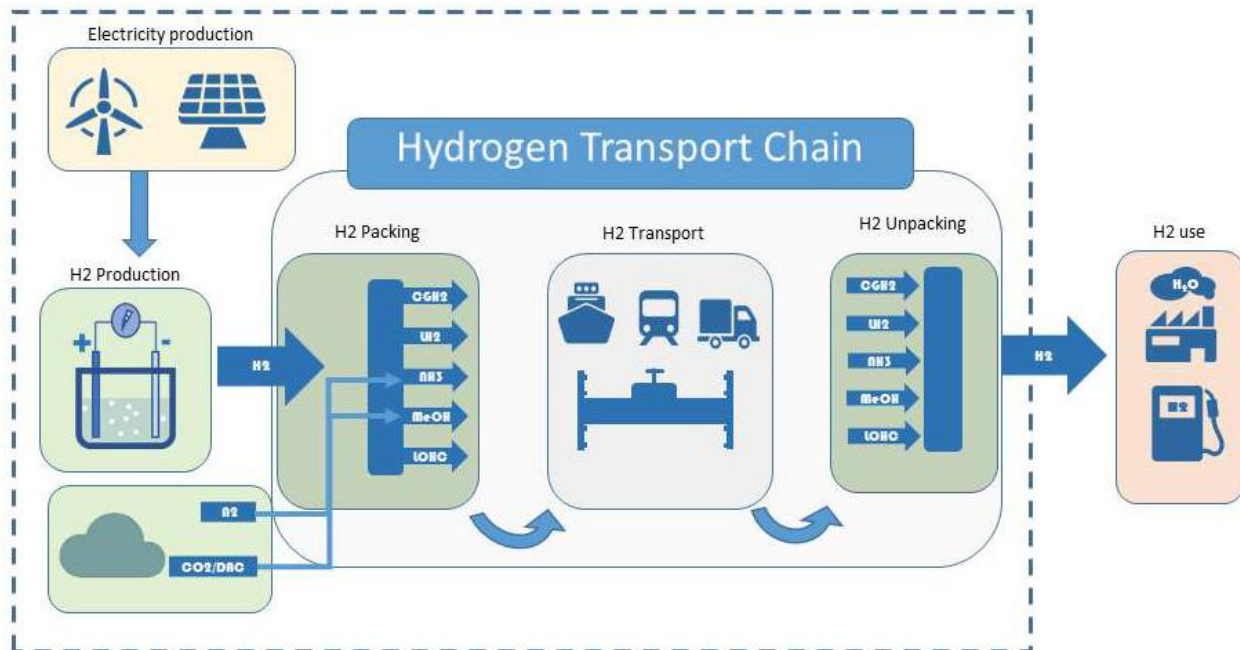


Figure 1 - Full Hydrogen Value Chain. Source: JRC, *Hydrogen, electrolyzers and fuel cells for a decarbonised and Sustainable Europe*, The Joint Research Centre: EU Science Hub

Water electrolysis

Electrolysers split water into hydrogen and oxygen using electricity, while fuel cells use hydrogen to generate clean heat and power efficiently. Hydrogen production can be carbon-neutral when the electricity comes from renewable sources, and electrolysis is expected to progressively replace today's CO₂-emitting steam methane reforming.

For practical planning, mature alkaline (AEL) and PEM electrolysers from emerging high-temperature options (rSOC/SOEC) are distinguished. AEL typically operates at $\leq 90^{\circ}\text{C}$ and ≤ 30 bar, delivers about 65-70% efficiency (excluding heat) and has the lowest capex. PEM can reach roughly 65-83% efficiency and is strong in fast load-following, but faces cost and stack lifetime constraints. rSOC/SOEC is promising for higher efficiency—especially when heat is available—but is not yet broadly commercial.

Project feasibility depends strongly on-site utilities and balance-of-plant: water must be demineralised, supply can combine grid water, rain harvesting, or nearby water bodies, and developers must account for permitting, pumping and demineralisation energy, and capex/opex to size tanks, pre-treatment and auxiliaries. For “renewable” hydrogen certification, Delegated Regulation (EU) 2023/1184 sets requirements (e.g., direct line versus grid-sourced electricity with additionality and temporal/geographic correlation, and an emissions threshold pathway). Electrolysers are also treated as “energy storage” within electricity market rules, influencing ownership and grid-access models.



Electrolysis is a key technology for renewable hydrogen and can support wider energy-system integration by providing grid services (e.g., aFRR/mFRR) and by valorising waste heat to on-site users or district heating. Although demonstrations are scaling up—including projects connected to electricity and gas grids—important gaps remain on achievable performance and costs and on where electrolysers best meet policy and market needs, which helps explain limited commercial deployment in heavy industries and transport.

Because electrolysers consume large amounts of electricity and generate significant waste heat, recovering and reusing this heat is an important opportunity to increase overall efficiency, reduce primary energy demand, and support decarbonisation—especially for heating and industry. To track progress, harmonised measures and testing protocols for performance, durability, degradation and efficiency are required; JRC testing methods help compare electrolyser types under realistic operating conditions.

Finally, solid oxide electrolysis (SOEC) uses high-temperature electrolysis with both electrical and thermal energy. It can exploit waste heat and may reduce energy consumption by around 20-30% compared with low-temperature electrolysis, making it a particularly efficient pathway for green hydrogen where suitable heat sources exist.

Testing of hydrogen pipelines and high-pressure hydrogen storage systems

Hydrogen pipelines move hydrogen gas typically at 15-100 bar and require dedicated safety-by-design and material choices because hydrogen behaves differently than other gases. Hydrogen storage is most commonly done as compressed gas in high-pressure tanks (about 350-700 bar) for both mobile and stationary uses, with alternatives such as cryogenic liquid storage or solid-state storage.

At EU level, the RePowerEU Plan highlights hydrogen infrastructure as essential to connect supply and demand and speed up hydrogen adoption in industry and transport, with expansion expected to rely largely on repurposing existing natural gas pipelines, supported by new dedicated lines. In Germany, recent measures relevant to future hydrogen backbones—such as a hydrogen network tariff ordinance, a guarantee-of-origin registry for green hydrogen, and streamlined permitting via a Hydrogen Acceleration Act—aim to ensure verification, fair network access, and clear tariff setting.

Finally, market acceptance depends on standardised safety verification and validation methods for gaseous hydrogen infrastructure, including testing approaches like fast filling tests, gas cycle tests, and permeation tests.

Fuel Cells

Hydrogen fuel cell technologies convert the chemical energy of hydrogen into electricity through an electrochemical reaction with oxygen, producing only electricity, water, and heat. This clean process powers various applications, including vehicles, stationary power systems, and portable devices, with benefits like high efficiency and fast refuelling times compared to combustion engines. Different types of fuel cells exist, defined by their electrolytes, which affect their operating temperatures and performance.

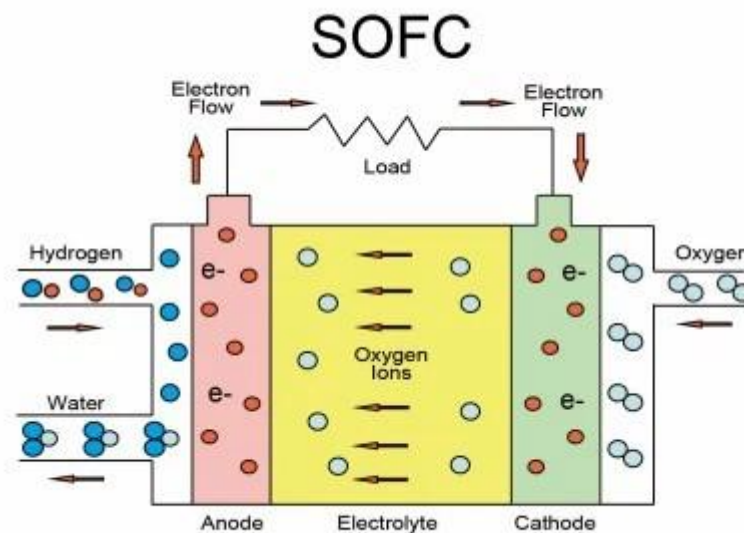


Figure 2 - Fuel Cells technology's process. Source: <https://stargatehydrogen.com/blog/hydrogen-fuel-cells/>

Organic Rankine Cycle (ORC) integration as a relevant option for hydrogen systems: an ORC can convert heat from sources such as solar, geothermal or waste heat into electricity using an organic working fluid (with a lower boiling point than water). That electricity can then power an electrolyser to produce green hydrogen, improving the overall utilisation of available thermal energy.

Fuel cells ($\geq 60\%$ electrical efficiency) are recognised CHP under EU efficiency rules; the DST models them with heat recovery into low/high-T TES and district heating, letting hubs stack power + heat revenues while meeting local air-quality goals.

SMR/reforming a waste heat

Steam Methane Reforming (SMR) is the most widely used hydrogen production method, using steam and natural gas at high temperatures to produce hydrogen and carbon monoxide, followed by further reactions that generate additional hydrogen and carbon dioxide (it is also associated with coal gasification routes). In parallel, thermochemical cycles powered by waste heat use residual heat from power plants or industrial processes to drive chemical reactions that recover energy which would otherwise be lost. These approaches can be integrated: waste heat can support thermochemical cycles and/or improve the efficiency of reforming processes, while the resulting hydrogen can be used as a cleaner fuel or industrial feedstock. This integration increases overall system efficiency and sustainability by maximising energy recovery.

Cracking of ammonia ($\text{NH}_3 \rightarrow \text{H}_2$) with waste heat

The cracking of ammonia into hydrogen and nitrogen uses heat, and a method that incorporates heat recovery from the process to utilize waste heat is more energy-efficient and cost-effective. This approach involves using heat exchangers to recover thermal energy from the hot output gases to pre-heat the incoming



ammonia, reducing the external energy required to break down the molecules, which are an endothermic process. This creates a more circular and efficient system that minimizes energy consumption.

In Annex 1 you may find the technology maturity map.

5.2. Drivers of H2 application

The section below illustrates the main drivers accelerating (and, in some cases, constraining) the uptake of hydrogen applications, with a focus on the evolving market dynamics that shape investment decisions and project bankability. It first examines economic drivers, highlighting global demand trends, regional market signals, and the role of public support schemes and early offtake agreements in bridging the current cost gap. It then discusses regulatory drivers and the way EU-level legislation and delegated acts are being transposed and operationalised within Central European national frameworks. Finally, it reviews national strategies and key market players, outlining how governments and major industrial actors are positioning themselves across the hydrogen value chain and how their choices are influencing the emergence of hydrogen hubs and broader regional ecosystems.

5.2.1. Economic drivers

Global hydrogen demand exceeded 97 Mt in 2023, but the recent increase largely reflects broader macroeconomic dynamics rather than a clear signal of effective policy delivery. On the supply side, China has consolidated leadership in electrolyser manufacturing and deployment (holding the majority share in 2024/25), yet domestic offtake remains a structural bottleneck; the resulting overcapacity is pushing equipment prices downward worldwide while raising questions around quality assurance, bankability, and logistics. In the United States, scale-up is primarily shaped by the 45V tax credit and the Hydrogen Hubs programme, with policy uncertainty remaining the principal watch item for investors and offtakers.

Beyond the established markets, Southeast Asia presents sizeable opportunities: ammonia and methanol production in Indonesia, Malaysia and Viet Nam could reduce reliance on imported natural gas, while rising steel demand in Indonesia and Viet Nam creates potential for hydrogen-based steelmaking routes. Singapore is strategically positioned to act as a maritime bunkering hub for international shipping. Across these regions, successful scale-up will depend on faster renewables deployment (to reduce LCOH), targeted fuel-switching policies, and well-designed pilot projects that bridge early adoption to commercialisation.

In the European Union, hydrogen demand is the most explicitly policy-driven, shaped by RED III, auctions and carbon-cost instruments such as CBAM. Export-oriented regions (e.g., MENA, Australia, Latin America) are increasingly aligning project design and certification to EU/US requirements to preserve future trade optionality. Within the EU, Germany's policy and financial package (including the national hydrogen strategy framework, IPCEIs/KfW instruments, and the first CCfDs announced in October 2024) is explicitly designed to close the "green premium", de-risk final investment decisions, and accelerate early industrial switching. Italy is combining participation in IPCEI Hy2Tech with a national strategy update and forthcoming tariff/market incentives under the competent authorities. However, evidence from stakeholder interviews (D3.2.2) suggests that 2030 targets are widely perceived as over-ambitious: several experts expect below



-8 Mt of actual EU production by 2030, citing gaps in import strategy, the absence of stable cost benchmarks, and uneven national implementation—particularly on permitting and regulation. Even where support schemes are generous, power price volatility, long grid-connection lead times, and still-immature offtake markets keep many projects in “price-discovery” mode; several partners describe the market as “too early” without targeted support and/or long-term contracts.

Industry is nonetheless responding: the number of offtake agreements is increasing and is progressively shifting from MoUs toward firm contracts, supported by tenders and cooperative initiatives aimed at aggregating demand for hydrogen and hydrogen-based fuels/feedstocks. Today, the chemicals, refining and shipping sectors concentrate the largest volumes of contracted demand and the largest share of firm agreements. The expected strengthening of carbon-cost pass-through in the EU context—particularly as CBAM becomes fiscal on 1 January 2026 for covered imports (e.g., steel, cement, fertilisers)—is also expected to improve the relative competitiveness of low-carbon hydrogen derivatives in EU markets. Several large-scale low-emissions hydrogen projects serving refining, chemicals and steel reached FID last year, signalling progress where policy support, infrastructure readiness and bankable offtake converge. Transport trends remain mixed: road transport is slowing with focus moving from passenger cars to heavy-duty vehicles, while shipping and aviation show growing interest where policy support is credible—though slow market penetration has already led to the cancellation of some ambitious supply projects. In the power sector, momentum is strongest in Japan and Korea, where large demonstrations are advancing and governments have launched early auctions for hydrogen- and ammonia-based power generation.

Overall, hydrogen production and demand are still best characterised as a policy-led, price-discovery market. Auctions (EU), tax credits (US) and carbon leakage tools (CBAM) are narrowing the cost gap, but bankable demand and infrastructure availability remain the key near-term swing factors.

Against this market backdrop, the literature consistently shows that EU hydrogen demand rises steeply from 2030 to 2050, but with wide dispersion depending on climate ambition, technology costs and the role assigned to hydrogen across end-uses. Comparative scenario families (e.g., EHB/Guidehouse, Deloitte/CHJU, ENTSOG, EC, JRC, Aurora, McKinsey) typically diverge based on three drivers: (i) the level of decarbonisation ambition, (ii) assumptions on electrolysers/renewables/CCS costs and deployment pace, and (iii) the extent to which hydrogen is used for power-sector flexibility (peaking generation, seasonal storage, and broader Power-to-X coupling). A common structural pattern nevertheless emerges: industry dominates early, while transport (and, in some pathways, power) scales materially after 2040. For more details, please refer to Annex 2.

- 2030: total demand ranges roughly 223-767 TWh (median ~344 TWh). Industry typically accounts for the bulk (often >70-80%), driven by refining and chemical feedstock substitution and initial hydrogen-based steel deployments. Transport is present but secondary; buildings and power appear only in selected scenarios. Please see Annex 3 to get an overview of the average per demand category in 2030.
- 2040: totals span about 388-1,490 TWh (median ~959 TWh). Transport expands (especially heavy-duty and parts of maritime), and power becomes visible in pathways with strong sector coupling and flexibility needs. Industry remains the anchor but its percentage share declines versus 2030. Please see Annex 4 to get an overview of the average per demand category in 2040.



- 2050: the range widens substantially (-198-4,818 TWh; median -1,386 TWh). The upper tail is typically driven by scenarios that assume extensive P2X and deep system flexibility needs. In several families, transport approaches or exceeds industry demand; power becomes material where hydrogen is assumed to provide seasonal storage and adequacy services, while buildings generally remain residual and intermittent across studies. Please see Annex 5 to get an overview of the average per demand category in 2050.

In conclusion, the trajectory across scenarios is one of monotonic growth in total demand and across most end-use categories, but with persistent structural uncertainty. Industry grows in absolute terms while gradually losing share as transport (and sometimes power) scales; transport evolves from an emerging segment to a co-leader by 2050 in pro-decarbonisation pathways; buildings remain marginal in most projections; and the power-sector role is optional and highly scenario-dependent, typically becoming significant only after 2040. Please see Annex 6 to get an overview of the average demand per category through the years.

LCOH breakdown

Levelised Cost of Hydrogen (LCOH) is a financial metric employed to evaluate the comprehensive economic feasibility of hydrogen production across its complete lifecycle as a €/kgH₂ figure. The Levelised Cost of Gas (LCOG)'s formula is the lifetime CAPEX and OPEX divided by the lifetime hydrogen production, with all values being discounted to their present value:

$$LCOH = \frac{CAPEX + \sum_{t=1}^T \left(\frac{OPEX_t + REPEX_t}{(1+d)^t} \right)}{\sum_{t=1}^T \frac{(1-t \times TDR) \times M_{H_2}}{(1+d)^t}}$$

Where CAPEX is the present value of all costs including direct costs and project overhead costs occurring before the start of the project, in year 0, including expenditures on engineering and preliminary study, purchasing the equipment and installation, site preparation and construction, and working capital. OPEX includes all operations- and maintenance-related costs on an annual basis for year $t \in [1, T]$, where T is the project lifetime. REPEX denotes the costs that will ensue from necessary replacement of the components in the plant, depending on the lifespan of the involved equipment.

That's why the Levelised Cost of Hydrogen (LCOH) is highly sensitive to renewable electricity price, often accounting for over 70% of the total cost. Because of this green hydrogen requires renewable electricity prices below \$20-\$30/MWh to compete with fossil-based hydrogen.

It is followed by electrolyser CAPEX, which is declining due to technological improvements and supply chain scaling. It can decline because of different factors:

- Larger-scale production reducing per-unit costs;



- Ongoing innovation and increased Technology Readiness Levels (TRLs) improving efficiency and reducing manufacturing costs.
- Policies like tax credits

Electrolyser efficiency is also critical, as higher efficiency reduces the amount of electricity needed per unit of hydrogen, thus lowering costs, especially for more efficient advanced electrolyzers. Electrolyzer efficiency can, indeed, vary and decreases at off-design (fluctuating) operating points, which can lead to overestimating production volumes if not accounted for.

Technologies like Solid Oxide Electrolysis Cells (SOECs) have high efficiency, which helps distribute costs and maintain a low LCOH, despite potentially higher heating costs.

Cost ranges (€ per kg H₂) for different production methods

Clean hydrogen production costs are between 1.7 and 10.2 EUR/kg, but it depends on the way of producing hydrogen. Hereby, an explicative diagram showing the sensitivity assumptions of LCOH:

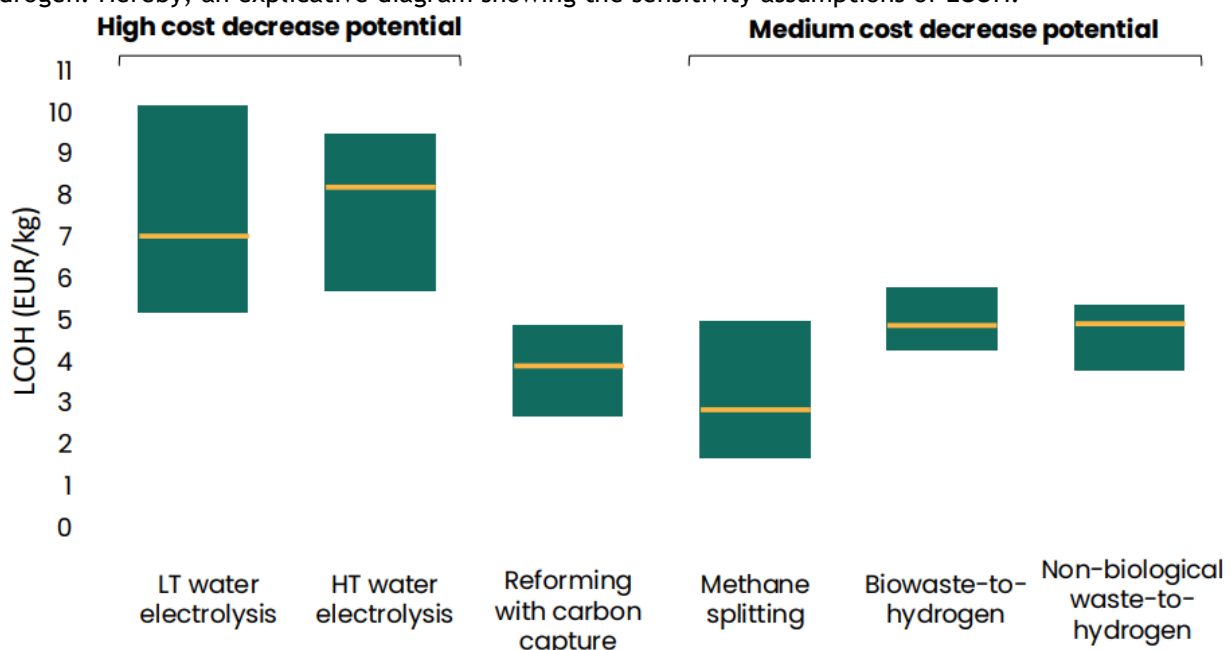


Figure 3 - Range of LCOH shown in the report using sensitivity assumptions. Source: Muron, M., Pawelec, G. and Fraile, D. (2024) CLEAN HYDROGEN PRODUCTION PATHWAYS - REPORT 2024

- **Water electrolysis** is most expensive pathway today but presents largest cost reduction potential: while best locations with access to low-cost electricity can present a strong business case, in most cases, costs are too high and FID's are often conditional on the project receiving subsidies. However, since costs are mostly driven by renewable electricity costs and CAPEX - both of which are expected to fall, water electrolysis also has the largest cost reduction potential among the analysed technologies. Electrolysis costs swing with: (i) power price & CF, (ii) stack life/degradation and replacement (REPEX), (iii) BOS: water treatment, compression, storage, (iv) heat/O₂ valorisation and DR.



- Reforming with carbon capture is among the most cost competitive, and with natural gas costs (the largest cost driver) still above pre-war levels, its cost could fall further. There is however significant uncertainty over CO₂ storage and transportation costs. Since gas reforming is a relatively mature technology CAPEX is unlikely to fall down.
- For methane splitting, natural gas costs are also the largest cost driver, but solid carbon byproduct revenues allow to reduce the final LCOH by 34%.

In case of both waste-to-hydrogen technologies CAPEX is the largest cost driver and has significant potential to decrease. The business case is also driven by feedstock type cost/revenue, byproduct revenues, and CO₂ transportation and storage costs, all of which are very project specific. However, limited deployment so far creates cost uncertainty.

5.2.2. Regulatory drivers

CE national regulatory framework

Eu-Commission have implemented different regulations, which have adopted and/or shaped in their countries' context:

- “European Climate Law” (Regulation (EU) 2021/1119): provides the overarching legal foundation for EU hydrogen policy by making the climate transition legally binding. It indicates the EU-wide objective of achieving climate neutrality by 2050 and sets an intermediate 2030 target of at least a 55% net reduction in greenhouse-gas emissions compared to 1990. Beyond targets, it strengthens the governance logic of EU climate action by requiring coherence between EU and national measures and the long-term trajectory, which in practice increases the importance of policy consistency and credibility for investment decisions in hydrogen production, infrastructure and end-use switching.
- Renewable Energy Directive (Directive [EU] 2018/2001 - RED III): a central demand-side driver because it anchors the EU’s 2030 renewable energy framework and translates it into implementation obligations that affect fuels and end-uses. By reinforcing renewable deployment and sectoral decarbonisation requirements, it increases the need for renewable molecules—especially in segments where electrification is difficult. Crucially, RED III also acts as the legal “gateway” for renewable hydrogen and its derivatives by establishing the accounting and sustainability logic for RFNBOs and explicitly relying on delegated acts to define the technical conditions under which hydrogen can be claimed as renewable. In parallel, the directive’s emphasis on accelerating renewables deployment is relevant for hydrogen economics, because large-scale, affordable renewable electricity is a pre-condition for competitive renewable hydrogen.
- Delegated Regulation (EU) 2023/1184: operationalises the RED framework by defining the methodology that determines when electrolytic hydrogen and other RFNBOs can be labelled “renewable.” In practical terms, it is the rulebook that project developers and offtakers must comply with to access support schemes, meet quotas, and make credible contractual claims. The regulation introduces core compliance pillars such as additionality (ensuring hydrogen production is linked to new renewable generation or equivalent conditions), temporal correlation (matching the timing of renewable electricity generation with electrolyser consumption), and geographical correlation (constraints linked to where the renewable electricity is produced relative to where it



is consumed). It also frames lifecycle emissions accounting and related eligibility conditions. These requirements materially shape project design choices (PPAs vs. direct connection, operating profiles, siting, and contracting structures) and therefore influence costs and bankability.

- Directive (EU) 2019/944: matters for hydrogen because electrolyzers are fundamentally electricity-driven assets and their business case depends on how they can participate in the power system. The directive strengthens the framework for flexible demand and market participation, enabling consumers and “active customers” to respond to price signals and, where applicable, participate through aggregation and demand-response arrangements. Its provisions on dynamic pricing contracts, switching rights, and the enabling environment for aggregation are particularly relevant for electrolyzers that optimise operations based on hourly price spreads or aim to monetise flexibility. In addition, the directive’s rules on metering, billing and data access support the practical settlement and monitoring needed for advanced operating models and participation in flexibility schemes.
- Directive [EU] 2024/1788: is pivotal because it establishes a modern EU framework for the internal markets of renewable gases, natural gas and hydrogen—effectively providing the regulatory architecture for hydrogen networks to emerge as a governed market rather than a collection of isolated projects. It clarifies market organisation and network governance for hydrogen, including roles and responsibilities linked to network operation and planning, and it introduces principles aimed at ensuring fair access—through unbundling/independence requirements and rules on third-party access and tariff setting. These elements directly affect how hydrogen infrastructure can be financed and accessed, and they reduce uncertainty for investors and industrial users by standardising the conditions under which hydrogen can be transported and traded. Finally, the directive’s transposition requirement means that timing and quality of national implementation become critical for “regulatory readiness,” influencing when projects can move from development to investment and operation.

According to the previously-introduced national strategies, hereby you can find the most important regulations, adopted by each country involved in HyEfre project. To deepen each regulations, we recommend you to take a look to D.2.2.1 - Economic Framework assessment report and D2.1.1 - Policy Framework Assessment Report, which have been summarized in Annex 7.

5.2.3. CE national strategies

The EU initiated this change through a series of strategies that have been further elaborated in subsequent documents. A portion of these strategies has already been integrated into legal norms.

The most significant strategic papers encompass the following:

- Clean Energy For All Europeans (2016)
- The European Green Deal (2019)
- A hydrogen strategy for a climate-neutral Europe (2020)



- Sustainable and Smart Mobility Strategy - putting European transport on track for the future (2020);
- 'Fit for 55': delivering the EU's 2030 Climate Target on the way to climate neutrality (2021)

National strategies, born from the CE ones, all have different points in common:

- Decarbonise hard-to-abate sectors (industry first; transport next).
- Deploy electrolysers and RES integration to build domestic H₂ supply.
- Build enabling infrastructure (refuelling stations, pipelines/repurposing, storage).
- Use public finance to de-risk first projects (grants, loans, IPCEI, recovery funds).
- Back R&D and demonstrations (hydrogen valleys, pilots, innovation programmes).
- Develop/align regulation (standards, permitting, guarantees of origin)—some mature, some still in progress.
- Coordinate national-regional action (state/Länder/region programmes) and plug into EU instruments.

In Annex 8 you can find an elaboration of D2.2.2's strategies with detailed insights of the taken actions, main foreseen goals and peculiar aspects per each country taken into account.

Main Players and their hydrogen strategies

In the emerging hydrogen economy, different categories of actors are playing clearly differentiated but complementary roles. Energy majors, utilities, industrial gas companies, technology providers and vehicle manufacturers are all building distinct strategies that, taken together, shape the development of hydrogen valleys and regional ecosystems.

Energy majors such as **ENI**, **Shell** and **TotalEnergies** are leveraging their existing portfolios in gas, refining and large infrastructure to position hydrogen as a key pillar of their long-term decarbonisation strategies. **ENI** mainly uses hydrogen to decarbonise its own refineries and chemical sites, starting from low-carbon hydrogen (reforming with CCS) and progressively scaling up green hydrogen linked to new renewable capacity. **Shell** focuses on integrated "hydrogen hubs" in ports and industrial clusters, where production, storage, pipelines and demand (industry and heavy-duty transport) are developed together. **TotalEnergies** is moving from refinery-focused projects towards a broader role as a global integrator of hydrogen value chains, including green hydrogen, green ammonia and e-methane connecting production regions (often outside Europe) to industrial off-takers within the EU.

Large utilities and network operators have a slightly different angle. Companies such as **Enel**, **E.ON**, **RWE**, **ENGIE**, **Iberdrola** and **Snam** tend to see hydrogen as complementary to electrification. Enel and Iberdrola focus almost exclusively on green hydrogen produced from dedicated renewable plants, targeting hard-to-abate industrial users (fertilisers, chemicals, refineries) through large integrated projects that combine renewables, electrolysers and long-term offtake agreements. **E.ON** is more a system enabler than a hydrogen producer: it concentrates on network planning, digital solutions and services for industrial customers, integrating hydrogen into broader decarbonisation and infrastructure packages. **RWE** and **ENGIE**



link green hydrogen projects to their renewable generation portfolios and to the development of H₂-ready power plants and power-to-X schemes. **Snam**, as a gas transmission system operator, positions hydrogen as the future content of its pipelines, working on repurposing gas infrastructure, developing an Italian and European hydrogen backbone and enabling large-scale transport and storage of hydrogen and CO₂.

Industrial gas companies and technology providers such as **Siemens Energy**, **Air Liquide**, **Linde** and **Bosch** mostly follow a technology- and service-driven strategy. **Siemens Energy** is investing heavily in large-scale PEM electrolyzers and wants to be the preferred supplier for multi-hundred-megawatt green hydrogen projects, often integrated with offshore wind or large PV plants. **Air Liquide** puts hydrogen at the centre of its growth strategy by combining electrolysis and reforming with CCS, building low-carbon hydrogen hubs that serve both industrial clients and mobility applications (trucks, buses, port equipment). **Linde** capitalises on its engineering capabilities and focuses strongly on blue hydrogen, especially in North America, where existing SMR/ATR technologies can be coupled with CCUS at scale. **Bosch** is entering the market as a supplier of PEM electrolyser stacks and hydrogen components, aiming to industrialise production and reduce costs.

Vehicle manufacturers, particularly **truck OEMs (Daimler Truck, Volvo Group, Iveco, Scania and others)**, follow a dual strategy combining battery-electric and fuel-cell trucks. They generally reserve hydrogen fuel-cell vehicles for long-haul, high-payload operations, where batteries alone are less competitive. Joint ventures such as **cellcentric (Daimler + Volvo)** develop dedicated fuel-cell systems for trucks, while **OEMs** collaborate with utilities, oil & gas companies and public authorities to create hydrogen refuelling corridors along major freight routes. In hydrogen valleys, these OEMs often represent the anchor demand on the mobility side, helping to justify investments in refuelling infrastructure.



6. Overview of Business cases

Hereby an overview of the hydrogen hubs, already introduced in D1.1.1 - Report on Best Practices Assessment:

6.1. Austria

OÖ Wasserstoff-Offensive 2030 - Upper Austria Hydrogen Initiative

Upper Austria Hydrogen Initiative (often framed as the “OÖ Wasserstoff-Offensive 2030”) follows an **industry-anchored cluster logic**. The initiative is conceived as a programme umbrella rather than a single asset: it combines a regional strategy board, a structured company-research network and dedicated funding instruments to coordinate multiple projects across the hydrogen value chain. The business logic centres on building credible early demand around energy-intensive industries (notably steel and adjacent industrial users), while simultaneously developing enabling assets such as electrolysis, storage concepts, initial pipeline links and sector-coupling demonstrations. The presence of a regional research centre and formal network governance is used to consolidate technical capacity, standardise approaches where possible and support a pipeline of investable projects.

From a **scalability perspective**, the Austrian model is designed to move from pilots and first commercial units toward larger deployments through modular replication across sites and sectors. Early lighthouse projects act as “de-risking blocks” that validate technologies, operational practices and permitting pathways before larger CAPEX is committed. However, scalability is also constrained by the current reality that many installations remain custom-built (first-of-a-kind engineering), which can slow roll-out and increase costs until standardisation and repeatable EPC models are achieved.

In terms of **revenue** structure, the cases are primarily anchored in (i) industrial offtake where hydrogen substitutes fossil-based inputs or grey hydrogen in processes, and (ii) system and market value when hydrogen assets can provide flexibility-related benefits (directly or indirectly) through optimised electricity procurement, operational scheduling and—in some configurations—services linked to storage and balancing. Additional revenue and value streams may come from the ability to market low-carbon products (where certification frameworks apply) and from learning spillovers that position local actors in the supply chain (engineering, components, O&M). Overall, revenues depend on securing sufficiently long-term, bankable industrial demand and on reducing exposure to electricity price volatility.

The material implies a clear need for **incentives** and public support, especially in early phases. High CAPEX, still-elevated LCOH and first-mover risks mean that projects typically require programmatic funding, grants, concessional finance, or other de-risking tools to close the cost gap versus conventional alternatives and to make financing feasible. In this context, **regional funding calls** and structured support programmes provide planning certainty and help convert strategic intent into a stable project pipeline.

Regarding **implementation complexity**, the Austrian cluster approach is explicitly meant to manage complexity through coordination, but the underlying projects remain technically and organisationally demanding. Complexity stems from multi-actor governance (industry, utilities, research bodies and public authorities), permitting and safety requirements, integration of production with storage/transport, and the need to align renewable electricity supply with industrial consumption profiles. Cross-sector coupling and



the emergence of hydrogen infrastructure (even at a regional scale) require careful sequencing to avoid “chicken-and-egg” dynamics between supply availability and bankable demand.

6.2. Croatia

North Adriatic Hydrogen Valley (NAHV)

Croatia participates in the North Adriatic Hydrogen Valley (NAHV), a transnational hydrogen valley developed jointly with Slovenia and Italy. The underlying **business logic** is to build an integrated value chain—from renewable hydrogen production to storage, distribution and multiple end-uses—so as to address the two core early-market constraints: limited bankable demand and insufficient infrastructure. The NAHV model relies on a large multi-actor consortium (37 partners) and a portfolio of testbeds covering several sectors (industry, energy, land transport and maritime uses), so that risks and investments are distributed and learning is accelerated across different applications rather than concentrated in a single project.

From a **scalability standpoint**, the Croatian component benefits from the valley’s portfolio approach: the model is designed to scale through replication of modular “testbeds” and progressive expansion of production and end-use volumes as operational evidence accumulates. Scalability is supported by the explicit intention to trade part of the hydrogen across the three territories (the project targets at least 20% cross-border trading), but it remains contingent on how quickly infrastructure and harmonised rules (certification, market access, network conditions) evolve in practice.

The expected **revenue structure** is multi-stream. It is primarily anchored in hydrogen sales to contracted end-users across different sectors, complemented by potential additional value from cross-border trading within the valley ecosystem. The integrated approach is meant to improve utilisation rates of shared assets (production, storage, logistics), which in turn supports more stable cash flows than single-offtaker models. However, the extent to which revenues can be made fully bankable still depends on the maturity of long-term offtake contracting for hydrogen and hydrogen-based fuels/feedstocks in the region.

The case also implies a strong need for **incentives** and public support, especially in early phases. NAHV is framed as a Clean Hydrogen / Horizon Europe-funded initiative, and that public backing is positioned as a central de-risking lever to mobilise investment across the value chain and to bridge the cost gap between renewable hydrogen and conventional alternatives. In this context, the **consortium structure** functions as an additional **de-risking mechanism** by enabling cost sharing, coordinated planning and a more credible scale narrative for investors and offtakers.

In terms of **implementation complexity**, the business case is inherently high-complexity because they are embedded in a **cross-border programme**. Complexity stems from multi-level governance and coordination among public authorities, private operators and research actors across three jurisdictions, as well as from the technical integration of production, storage, distribution and diverse end-uses. The material highlights typical risk categories linked to this complexity: coordination challenges, regulatory and policy gaps, and broader supply chain and technical risks, alongside the need to develop workforce and skills capable of operating and maintaining new hydrogen assets.

6.3. Czech Republic

Brno Hydrogen Public Transport (H2vBrno / Teplárny Brno)



The Brno case is structured as a **municipal-cluster** approach, where the city coordinates a local hydrogen value chain through the H2vBrno association (City of Brno, Teplárny Brno, DPMB, SAKO Brno and Brno University of Technology). The core business idea is to produce and use hydrogen locally for urban mobility, with Teplárny Brno preparing an “end-to-end” concept (production and use in the city system) and DPMB acting as the first anchor offtaker for buses.

The planned production scale discussed publicly is “up to 600 tonnes of hydrogen per year”, with a split between renewable hydrogen (up to ~150 t/y) and low-carbon hydrogen for the remainder—an approach that can support phased scaling (start with limited fleet conversion and expand as supply, funding and regulations allow). The cluster positioning also implies that additional municipal/urban uses (beyond buses) can be added over time as utilisation grows, because **multiple city-owned actors** are already part of the governance set-up.

The revenue logic is based on **contracted offtake**: hydrogen supply (and potentially refuelling service) sold to DPMB as fleet demand grows, with a “municipal counterparty” profile rather than relying on dispersed retail customers. A second revenue layer is linked to public funding streams for zero-emission rolling stock and infrastructure, which can reduce the amount of private capital that must be recovered through hydrogen sales.

The Czech Modernisation Fund has dedicated support for zero-emission public transport (including hydrogen buses) and related infrastructure; the IEA policy summary reports a CZK 7.3 billion programme with support levels linked to eligible cost differentials. This **incentive environment** matters for Brno because the business case is still sensitive to the “green premium” (vehicle CAPEX and hydrogen supply costs versus conventional options), especially in the early deployment phase.

Complexity is driven by multi-asset integration (production + storage + refuelling + fleet conversion) and multi-actor governance (city + utility + operator + waste company + university), which typically increases permitting, safety management, procurement coordination and operational interface risks compared with single-asset projects.

ČEZ / Mníšek pod Brdy Project (Central Bohemia)

This is a **regionally-procured public transport** pilot where the bus operator (Martin Uher Bus, within the Integrated Transport System) runs hydrogen buses under a service contract, while ČEZ ESCO supplies the hydrogen “ecosystem” (electrolyser, storage and refuelling station). The project is designed around a defined operational geography (hilly routes around Mníšek pod Brdy), which supports a controlled demonstration of performance and operating costs in real service.

The initial scale is intentionally bounded—10 fuel-cell buses entering service at the end of 2025, with a public statement from regional stakeholders that the concept could be expanded to other areas if the operating model proves robust. The hydrogen production and dispensing assets are specified as a complete starter system: a 540 kW electrolyser, a refuelling station, and onsite storage with a total capacity of ~500 kg of hydrogen. Annual utilisation is described at about 550,000 km/year, with the fleet consuming up to ~45 tonnes of green hydrogen per year—figures that can be used as a baseline for scaling scenarios (e.g., adding fleets or extending service corridors).



The **revenue logic** is primarily two-tier. First, the transport operator's revenues derive from the **public transport service contract** (typical gross-cost or net-cost arrangements under regional integrated transport). Second, the **energy-side revenues** are linked to supplying hydrogen (and associated refuelling services) to a captive fleet; this reduces classic "retail HRS" utilisation risk in the early phase because demand is pre-defined by scheduled operations.

The project's capex profile is explicitly **subsidy-supported**: most acquisition costs are covered by EU funding instruments (IROP and the ITI programme for metropolitan development). This confirms that—at least for first-of-a-kind deployments—the model depends on public co-funding to overcome the initial cost gap (vehicles + production/refuelling infrastructure).

Complexity comes from **coordinating** four moving parts on a fixed deadline: bus procurement and commissioning, electrolyser and HRS delivery, renewable electricity sourcing, and safety/regulatory approvals for hydrogen production/storage/refuelling. The project also has a defined green electricity supply link (hydropower from the Vrané nad Vltavou plant) to ensure low-emission hydrogen, which adds contractual and operational interfaces between the power asset and hydrogen production.

6.4. Germany

GET H2 Nukleus (Lower Saxony)

GET H2 Nukleus is designed as a **backbone-first industrial decarbonisation** case: it links large-scale green hydrogen production in Lingen with major industrial consumers in North Rhine-Westphalia through an initially ~130 km hydrogen network, positioned as one of the first regulated, non-discriminatory-access hydrogen networks with transparent pricing. A key feature is the focus on repurposing/connecting infrastructure as part of the emerging hydrogen core network, with the overall scheme framed as IPCEI-eligible building blocks.

The project is conceived for stepwise scale-up: sources describe a first step connecting green hydrogen production from a 300 MW electrolysis plant to industrial customers, alongside integration of cavern storage (Gronau-Epe), creating a platform to expand volumes and add users over time.

Revenues are primarily anchored in (i) **long-term industrial offtake** (refining/chemicals/industry in the corridor), and (ii) **regulated network** revenues under transparent tariff/access conditions—i.e., a shift from "project-by-project pipes" to a network-style infrastructure business.

Public de-risking is a structural pillar: RWE reports a EUR 492 million funding commitment (federal government with Lower Saxony) linked to implementing the project under the IPCEI framework. At system level, the hydrogen core-network framework is also being supported through **tariff regulation** intended to provide planning certainty in the ramp-up phase.

Complexity is high because the case integrates multiple regulated and technical layers: electrolysis at scale, storage connection, pipeline repurposing/new build, and multi-shipper access rules. Coordinating permitting, safety, commissioning and market access across several industrial nodes and operators is a non-trivial delivery challenge.

Hamburg Green Hydrogen Hub (HGHH)



HGHH follows a **port-industrial hub model** built on brownfield reuse: a 100 MW electrolysis facility at the former Moorburg coal plant site is intended to supply green hydrogen to port, industrial and mobility users, turning existing energy-site infrastructure into a new hydrogen production node. Public communications frame the project as a cornerstone for Hamburg's port decarbonisation and industrial transition.

The hub targets around 10,000 t/year of green hydrogen and is planned for commercial operation in 2027, creating a large anchor volume that can support downstream distribution and additional offtakers. Distribution is planned via the local hydrogen distribution network (HH-WIN) and trailer logistics, which supports progressive market build-out beyond the plant fence.

Revenues combine (i) hydrogen sales to **diversified offtakers** (port/industry/mobility), and (ii) **infrastructure-enabled service** revenues (distribution via a dedicated network and trailer loading), which can reduce reliance on a single anchor client by widening the customer base.

The project is explicitly **subsidy-supported**: Hamburger Energiewerke reports EUR 154.1 million in combined federal/state funding for the hub (with Luxcara as partner), awarded in mid-2024.

The core **complexity** drivers are **brownfield conversion**, grid and hydrogen-network integration, and safety/permitting for a large electrolysis and compression system within an active port/industrial context. The delivery model also includes multiple institutional actors and public funding compliance requirements.

Hy2B Hydrogen Cluster (Pfeffenhausen, Bavaria)

Hy2B is a **cluster-with-mobility-anchor model** that scales supply before pipelines: a central production site supplies hydrogen by road to refuelling stations and bus fleets, using public transport as the anchor demand while building a broader regional market. It emphasises integration with regional innovation infrastructure (hydrogen centre / HyBayern context).

Public sources describe a 5 MW electrolyser in Pfeffenhausen, with expected output around 440 tonnes/year once in regular operation, and electricity supplied from a nearby solar park (reported as 10 MW in media coverage). This provides a modular base: additional electrolysis and distribution capacity can be added as fleet numbers and station throughput rise.

Revenues are centred on contracted supply to mobility offtakers (notably bus operations) and sales via refuelling stations, which provides clearer utilisation than purely retail HRS models in early phases (because bus demand is route- and timetable-driven).

The case is typically dependent on **public support** for early fleet deployment and infrastructure, consistent with the broader German approach of reducing early adoption barriers for zero-emission heavy transport through fiscal and regulatory measures.

Complexity is moderate-to-high: while road distribution avoids immediate dependence on pipelines, the project still requires coordinated delivery of electrolysis, compression/storage, transport logistics, and station deployment—plus safety approvals and operational readiness for public transport fleets.

Frankfurt-Rhine-Main regional hydrogen distribution network (Rh2ein-Main Connect)

This case is a **regional distribution network play**: utilities and network actors plan a dedicated hydrogen distribution grid to connect local production/storage and end-users (industry, transport, potentially heat



and power), while linking the metropolitan region to Germany’s hydrogen core network through several connection points. The approach mirrors a “stitching” logic—building local distribution capability that becomes valuable once core-network flows materialise.

The project is explicitly **phased**. Public statements indicate first sections expected to enter operation from 2028, with the network planned to reach around 300 km in total length, and an initial build-out horizon to 2032, including the repurposing of existing natural-gas pipelines.

Revenues are expected to follow a **network-utility logic**: regulated/structured distribution fees for connected users, plus potential contracted capacity bookings once industrial and mobility demand is firm enough to justify connections. The bankability is therefore strongly tied to (i) connection pipeline timing, and (ii) the credit quality and permanence of connected demand.

As with most early hydrogen networks, public support and tariff design are critical in the ramp-up phase to avoid prohibitive network charges when user numbers are still low; Germany’s regulator has been actively setting ramp-up conditions for the core network to create planning certainty.

Complexity is high because it is a multi-stakeholder infrastructure programme with long lead times: routing and permitting, pipeline conversion, safety demonstration, connection agreements with end-users, and synchronisation with the national core network’s rollout schedule.

Wunsiedel (WUN H2, Bavaria)

WUN H2 is a **regional anchor plant model**: it produces green hydrogen at the Wunsiedel Energy Park using renewable electricity, supplying regional industrial/commercial customers and mobility use cases, with a narrative of “hydrogen from the region for the region.”

The commissioned electrolyser is reported at 8.75 MW (PEM) with output up to 1,350 tonnes/year of green hydrogen. This size is large enough to anchor a regional market while still being “replicable” as a template in other regions with similar RES availability and demand profiles.

Revenues mainly come from hydrogen sales to regional industry and transport users; the bankability improves when the customer base is diversified (multiple industrial and mobility clients) rather than relying on a single offtaker.

The case is often presented as part of a broader regional hydrogen strategy context rather than as a purely subsidy-driven plant; however, like most early green hydrogen production, its competitiveness remains sensitive to electricity prices and the ability to secure long-term demand at a price that covers CAPEX and OPEX.

Complexity is moderate: the project concentrates production on one site and serves a regional radius, which reduces cross-border and multi-network coordination needs; nonetheless, it requires robust safety management, renewable power sourcing arrangements, and reliable logistics/dispensing for mobility customers.

6.5. Hungary

Budapest Hydrogen Mobility Project



This case is structured as a **mobility-first market seeding initiative**: demonstrate fuel-cell buses in real service (Budapest agglomeration first, then other cities) while simultaneously enabling refuelling through a first public station. The goal is to create an operational “nucleus” (vehicles + HRS + trained operators) that can later anchor a wider hydrogen corridor strategy.

The project is intentionally phased. In the pilot stage, a fuel-cell bus is deployed on a scheduled route in the Budapest agglomeration (Kelenföld-Szigethalom), with additional periodic deployments in major cities (e.g., Debrecen, Győr, Kecskemét, Kaposvár, Miskolc, Zalaegerszeg). Scaling is explicitly linked to Hungary’s National Hydrogen Strategy targets for 2030, which include 20 hydrogen refuelling stations / 40 refuelling points, ~4,800 fuel-cell vehicles, and ~10 kt/year of “green and other carbon-free hydrogen” for transport.

In early phases, **revenues** are primarily **policy-enabled** rather than purely market-based:

- **Public transport contracting** provides a predictable demand base for hydrogen (fleet operations under service contracts), while the HRS can gradually extend to other users as utilisation grows.
- The station itself was launched in a “demonstration” mode: during the test period, refuelling at Illatos út is free up to a stated volume, indicating that early operations are designed to generate learning and acceptance more than immediate commercial returns.

The dependence on **incentives** is explicit in the **national** framework. The National Hydrogen Strategy lists dedicated programmes and indicative budgets, including Green Bus Programme Plus (HUF 10-20 bn) and Green Truck Programme (HUF 35-40 bn), alongside hydrogen valleys and infrastructure initiatives. This confirms that early hydrogen mobility is expected to require public co-funding to bridge higher vehicle and fuel costs until scale and utilisation improve.

Complexity is high because it involves (i) fleet deployment across multiple cities, (ii) safe operation and training, and (iii) synchronisation of vehicle availability with refuelling capacity. The Illatos út station is operated by Linde and tied to HUMDA’s one-year bus demonstration, showing the need to align multiple institutions and operational timelines. The strategy also acknowledges that building the refuelling network is “critical” for transport uptake, implying permitting, safety cases, and sequencing challenges as the network expands.

MOL Green Hydrogen Refinery

This case follows a **classic refinery-integration model**: install an electrolyser on an existing industrial site and use the hydrogen internally to decarbonise fuel production. MOL positions the plant as a step toward lowering the refinery’s carbon footprint and supporting the company’s longer-term decarbonisation pathway.

The installed unit is 10 MW, supplied by Plug Power, with MOL stating it can produce ~1,600 tonnes of green hydrogen per year and reduce the Danube Refinery’s emissions by ~25,000 tonnes CO₂/year. **Scalability** is framed as **replication**: MOL explicitly indicates plans to implement similar green hydrogen plants at its refineries in Rijeka and Bratislava following Százhalombatta.

The primary value stream is **internal** rather than merchant hydrogen sales: hydrogen is used “primarily in its own network for fuel production,” so the return is linked to refinery economics—reduced carbon intensity, compliance value, and strategic positioning of products/processes under tightening climate



regulation. MOL has also signalled that green hydrogen could later be used directly in transport applications, which would open an external offtake path if/when a broader mobility market and refuelling network materialise.

Public sources available for this case emphasise the investment and operational outcomes rather than a grant-funded structure: MOL describes it as a €22 million project and ties it to corporate strategy and refinery decarbonisation. In practice, the “incentive” function here is largely the regulatory and carbon-cost environment (i.e., the economic value of emissions reductions and low-carbon production), rather than direct fleet-style subsidies.

Complexity is moderate-to-high but contained within a single industrial site: it requires integration with refinery utilities and operations, water treatment, safety management, and commissioning. After inauguration, MOL reported technical steps such as pressure testing, process control checks, and commissioning of the water treatment system before entering production.

6.6. Italy

H2 Valle Padana / A22 Hydrogen Corridor

The corridor logic is to seed hydrogen demand through **mobility first** (HRS along a strategic TEN-T motorway axis) and then connect wider regional uses as volumes grow. Autostrada del Brennero frames the initiative as a stepwise build-out starting from distribution/refuelling assets consistent with PNRR objectives.

The initial phase prioritises a distribution/refuelling plant sized for ~2,000 kg/day average refuelling, including storage, compression and multiple dispensers (350 bar HDV + 700 bar LDV), which is a scalable baseline for corridor throughput growth. **Scaling** typically depends on whether **supply shifts** from tube-trailer logistics to more permanent production and/or pipeline connection as utilisation rises.

Revenues are mainly **retail/wholesale refuelling margins** (hydrogen sales and refuelling services), with utilisation as the key driver (corridor projects are sensitive to early-stage “throughput risk”). A corridor can progressively improve bankability by adding captive users (public fleets, logistics operators) that stabilise demand.

The model is strongly linked to public support under the **PNRR**, which is used nationally to accelerate early HRS and hydrogen-valley assets and reduce first-mover costs in mobility.

Complexity is moderate-to-high: it requires **coordination** across motorway operator(s), permitting and safety authorities, station EPCs and hydrogen suppliers, with the additional challenge of synchronising station commissioning with the ramp-up of hydrogen vehicle fleets.

Puglia Green Hydrogen Valley

This is an **industry-anchored** hydrogen valley aimed at large-scale green hydrogen supply for hard-to-abate industrial demand (notably the Taranto industrial cluster), supported by an IPCEI structure that de-risks early investments.



Public sources describe the project in the 160-220 MW electrolysis range across sites, powered by large PV build-out³

The scaling pathway is therefore “**valley-scale**” from the start, with additional expansion linked to backbone connectivity and industrial switching pace.

Revenues are anchored in **industrial offtake contracts** (hydrogen as feedstock/fuel for industry) rather than retail mobility. The value proposition strengthens where hydrogen substitutes carbon-intensive inputs and where contractual structures can be long-term (industrial-grade bankability).

The European Commission approved up to €370 million under IPCEI Hy2Infra for the Puglia valley. This support is central to bridging the “green premium” during early industrial switching.

Complexity is high: multi-site development, large PV and electrolysis integration, industrial offtakers, potential blending/injection constraints, and synchronisation with hydrogen transport build-out (including Snam’s regional backbone investments mentioned alongside the project).

North Adriatic Hydrogen Valley (please refer to Chapter 6.2 Croatia)

Porto Marghera (Venice)

This is a **port-industrial cluster case**: co-locate renewable hydrogen production and high-pressure logistics within an existing industrial area to serve industrial and mobility demand while reusing brownfield context and existing infrastructure.

The facility is notable for 500-bar compression (logistics efficiency) and dedicated renewable supply (a dedicated PV plant is part of the project package), positioning it as a scalable logistics node for a wider port/industrial market.

Revenues combine hydrogen sales with value-added logistics (high-pressure distribution enabling larger transported volumes per trip and better utilisation of downstream customers). Co-location also reduces recurring logistics costs versus remote supply.

Sapio reports ~€20m total investment, with ~€17m financed by PNRR, including funding for electrolysis/compression and the PV plant component.

Complexity is high because it combines industrial brownfield permitting, high-pressure hydrogen systems, renewable electricity integration, and port-area stakeholder coordination.

Bolzano / South Tyrol hydrogen hub

³ Saipem’s release refers to 220 MW electrolysis and ~400 MW PV across Brindisi, Taranto and Cerignola. EDISON, SAIPEM, ALBORAN Hydrogen (2022) “EDISON AND SAIPEM JOIN TOGETHER IN A SPECIAL PURPOSE VEHICLE TO IMPLEMENT THE PUGLIA GREEN HYDROGEN VALLEY PROJECT”. Available at: https://www.saipem.com/sites/default/files/import/press_releases/PR%2008.09.2022_ENG.pdf

Reuters reports 160 MW electrolysis and 260 MW PV for Brindisi/Taranto in the IPCEI package. Reuters (2024), “EU awards Italian energy groups \$402 mln for green hydrogen”. Available at: <https://www.reuters.com/sustainability/climate-energy/eu-awards-italian-energy-groups-402-mln-green-hydrogen-2024-02-26>



The South Tyrol model is a **mobility-anchored**, co-located hub along a strategic Alpine corridor (Brenner): produce, store and refuel locally to ensure reliable fleet operation (buses/trucks) and demonstrate corridor feasibility.

The more recent Hydrogen Adige Valley development is described as a 5 MW green hydrogen facility in Bolzano Sud, supported by public funding for brownfield conversion and positioned to supply local public transport. The **scaling** logic is stepwise: add production/output and refuelling capacity as fleet numbers and corridor demand rise.

Revenues are primarily **fleet-of-take** (public transport operator demand), complemented by potential third-party sales where a local HRS network grows. Co-location reduces delivered cost per kg (logistics + reliability benefits).

The Adige Valley initiative is linked to **PNRR** funding for hydrogen assets on disused industrial sites, indicating continued reliance on public co-funding for early-stage scaling.

Complexity is moderate-to-high: while the hub benefits from long operational experience in the area, expansion requires tight coordination among province, operators, EPCs, and safety authorities, plus alignment with corridor-wide station spacing and supply planning.

H2iseO Hydrogen Valley (Lombardy)

This is a **captive-demand rail decarbonisation model**: replace diesel traction on a non-electrified line with hydrogen trains, supported by a dedicated hydrogen supply chain (production, storage, distribution) and a specialised maintenance/refuelling depot.

The project includes multiple production sites (electrolysis in Brescia/Edolo; a biomethane-to-H₂ pathway in Iseo as described by Trenord) plus the Rovato depot/refuelling facility, which is a scalable infrastructure base for expanding the hydrogen fleet and adding related road mobility uses.

Revenues are anchored in **public transport service continuity** (rail operations as predictable offtake) rather than merchant hydrogen trading: the business case is strengthened by long-term service planning and the ability to layer additional demand (e.g., buses) to improve utilisation of supply assets.

Sources refer to **public funding** (including PNRR-linked resources) supporting rolling stock and infrastructure, consistent with the early-stage nature of hydrogen rail economics.

Complexity is very high: rolling stock delivery, depot build-out, multi-technology hydrogen supply (electrolysis and other pathways), safety approvals, and strict synchronisation to avoid stranded assets (trains without fuel or fuel assets without trains).

Civitavecchia port hydrogen hub

This is a **seaport hydrogen valley model**: decarbonise port mobility (notably buses and port/retro-port vehicles) by pairing local renewable hydrogen production with a dedicated refuelling station and demonstration operations under LIFE3H.

The “H2 Civitavecchia” concept includes 3 MW electrolysis powered by 4.5 MW off-grid PV with electrical storage, with an estimated ~145 t/year of hydrogen production. The associated refuelling station (“HRS Civitavecchia”) is described with a first phase around ~397 kg/day and staged expansion logic.



Revenues are based on **captive port demand** (bus operations and port users), with a clearer utilisation profile than purely public retail HRS—especially if supply contracts are tied to scheduled services.

The project materials present **PNRR-funded** components (production in disused industrial areas; experimentation for road transport) alongside EU co-financed demonstration activity under LIFE3H.

Complexity is high: port-area safety constraints, multiple funding compliance streams (EU and PNRR), off-grid PV-battery-electrolyser integration, and stakeholder coordination (port authority ecosystem, mobility operator, infrastructure developer).

Italian H2 Backbone / South2 Corridor

This is the **infrastructure backbone business case** enabling large-scale market formation: an ~1,900 km Italian hydrogen transportation network (about 60% via conversion of existing gas infrastructure) positioned as a key element of the broader ~3,300 km South2 Corridor linking North Africa to Central Europe.

Scalability is **corridor-driven**: the asset is designed to grow into a multi-country import and distribution route, with expansion linked to compression capacity additions and downstream network connections.

Revenues follow a regulated network / tariff-based model (capacity and transport services), where bankability depends on regulatory frameworks, tariff setting and the pace at which shipper demand (industrial/mobility) materialises.

The project has received €24 million EU co-funding (for development studies and preparation activities) as part of EU energy infrastructure support, and it holds PCI-related relevance within the corridor framing.

Complexity is very high: multi-region routing, conversion engineering, cross-border interoperability, and synchronisation with both supply imports and domestic demand clusters—plus lengthy permitting and stakeholder engagement typical of large transmission assets.

6.7. Poland

ORLEN Hydrogen Hub - Włocławek (ANWIL)

This business case is built around **industrial integration and mobility market creation**: ORLEN purifies hydrogen at the ANWIL site in Włocławek to fuel-cell/automotive grade and uses it as a supply anchor for a national rollout of hydrogen refuelling stations under the “Clean Cities” programme, targeting public and freight transport as first customers.

Public sources describe a modular ramp-up from an initial capacity (reported around ~170 kg/h) towards up to 600 kg/h as demand grows, i.e., scaling production in step with station throughput and fleet uptake. On the downstream side, the third phase of Clean Cities alone targets 16 additional public HRS, indicating that station density and utilisation are expected to increase progressively rather than all at once.

The **revenue** model combines (i) hydrogen sales (and potentially refuelling service margins) via a growing HRS network, and (ii) anchor demand from public/freight fleets, which is critical to reduce early “throughput risk” (stations need volume to amortise CAPEX). The integrated model (production + logistics + stations) is intended to capture value across multiple steps of the chain.



ORLEN secured an EU non-repayable grant of EUR 62 million (April 2024) to support the third phase of Clean Cities, including additional refuelling stations and renewable hydrogen production linked to electrolysis powered by renewables.

Complexity is high because the case is not a single project but a coordinated rollout: it requires synchronising hydrogen production/quality assurance, distribution logistics, station permitting and safety approvals, and fleet deployments across regions—while maintaining compliance with EU funding conditions and evolving national rules for hydrogen activities.

PKP Cargo

The rail case is framed as an **R&D-to-deployment pathway for decarbonising freight operations**, starting with feasibility studies and partner alignment to develop hydrogen-powered shunting locomotives and freight wagons, with industrial hydrogen supply concepts (including hydrogen potentially derived from coking gas) discussed by the participating companies.

It begins with shunting (a more controlled duty cycle and refuelling pattern), then expands to broader freight operations if infrastructure and total cost of ownership become favourable. Public statements describe this as an early-stage cooperation framework rather than a fully commercial deployment programme, so **scalability** depends strongly on progressing from concept and prototyping to fleet procurement and fuelling availability.

The **revenue/return logic** is primarily **operator-side value**: reduced emissions exposure, improved ESG performance, potential operating cost stability if fuel supply contracts are secured rather than merchant hydrogen trading. Bankability, where it emerges, typically relies on public procurement or co-funding for rolling stock innovation and on predictable depot-based demand profiles that can justify dedicated fuelling assets.

It generally requires public support in early phases because rolling stock CAPEX and fuelling infrastructure are high and utilisation risk is significant. Poland's broader strategy and regulatory work to structure the hydrogen market is relevant as an enabling condition for later-scale investment decisions.

Complexity is very high: it requires tight coordination between rolling-stock development, safety approvals, depot refuelling design, hydrogen supply contracts, and network operations—plus the classic “trains vs infrastructure” synchronisation risk (vehicles can be ready before fuelling is available, or vice versa).

Mazovian Hydrogen Valley

This is a **valley-as-governance-and-portfolio business case**: an ORLEN-led cluster of 50+ entities coordinates multiple projects across production, distribution and use of hydrogen, while also covering R&D, skills (Hydrogen Academy) and regulatory-support activities. The valley frames hydrogen as both an industrial transition vector and a clean transport enabler (including airport/urban mobility initiatives such as HySPARK).

Scalability is achieved through **replication** of projects under a single umbrella rather than one large asset: the cluster model is intended to grow by adding new pilots, offtakers and infrastructure nodes over time, supported by shared coordination and workforce development capacity.



The valley's **revenue** logic is multi-stream and project-dependent: hydrogen sales (where production/offtake is contracted), service revenues from distribution/refuelling assets, and innovation-oriented funding linked to pilots and demonstrations. The cluster structure aims to reduce single-project fragility by diversifying end-uses and counterparties.

Public and EU-level support is embedded in the concept: HySPARK and the valley have been referenced in the context of the Clean Hydrogen Partnership ecosystem, indicating reliance on EU-backed demonstration/innovation pathways to bridge early market gaps.

Complexity is high because success depends on orchestrating many stakeholders (industry, research, cities, operators) and aligning multiple project timelines, permitting tracks, and procurement streams—plus ensuring regulatory readiness for hydrogen activities as the market scales.

Rybnik

Rybnik is a **city-led fleet anchor case** where the refuelling station is planned around a defined initial offtake: hydrogen city buses (NesoBus) operating in regular service, supported by a publicly accessible HRS under the NESO brand. The case is also framed as a local “hydrogen district” style nucleus, with vertical integration ambitions on the supplier side (vehicles and refuelling network).

The station opened as an early node and is now being expanded: a 2025 contract for an upgrade (new module and dispenser) is intended to increase capacity to support the growing bus fleet, with completion targeted by end of Q1 2026; operators have stated the site could become one of Europe's largest stations after the upgrade.

The **revenue** model combines (i) captive demand from municipal bus operations (predictable depot refuelling volumes) and (ii) public retail refuelling for additional users as the market develops. This mix is meant to raise utilisation and improve station economics compared with a purely retail early-stage HRS.

While the cited company communications focus on deployment and expansion, early hydrogen bus programmes in Poland generally rely **on public co-funding** because vehicle CAPEX and hydrogen costs remain above conventional options; this is consistent with the wider Polish approach of pairing deployment with supportive regulation and funding instruments for hydrogen mobility.

Complexity is moderate-to-high: it requires safe operation of a public HRS, reliable hydrogen supply logistics, fleet operations and maintenance readiness, and (crucially) navigation of evolving rules for hydrogen infrastructure and permits as Poland's hydrogen regulatory framework matures.

6.8. Slovenia

North Adriatic Hydrogen Valley (NAHV) (please refer to chapter 6.2 Croatia)

ECUBES - “Energy storage for distributed power generation with fuel cell tech” (Nova Gorica, Slovenia)

This Slovenian NAHV testbed is structured as a deployable, containerised **hydrogen-based storage and power solution** to supply energy in remote/off-grid or constrained-grid contexts, supporting either hydrogen mobility (refuelling station support) or EV charging. The concept integrates hydrogen production/storage with fuel-cell electricity generation to provide on-demand power close to the point of use.



The system is designed for **replication** across multiple sites: the catalogue describes deployment across five locations in three countries and a technology maturation pathway from TRL2→TRL6 (tested at Salanit cement factory) toward TRL8 with broader testing. It targets ~1 MWh storage capacity using a liquid hydrogen carrier and is framed as a basis for a subsequent feasibility study for larger-scale investment.

The **revenue** logic is service-oriented rather than commodity-only: (i) provision of reliable distributed electricity (energy-as-a-service) for community/remote users, (ii) enabling revenues linked to charging/refuelling services where paired with mobility infrastructure, and (iii) the catalogue explicitly references carbon credit tracking to quantify and monetise emissions reductions as an additional value layer (where markets/rules allow).

As an innovation testbed, it is positioned within NAHV's **EU co-financed framework**; early deployment is therefore expected to rely on project funding and innovation support until unit economics and standardisation improve. The catalogue references a total project budget for this testbed of €5.6517m (covering hydrogen production, storage and equipment).

Complexity is moderate-to-high: while containerisation reduces site works and can simplify deployment, the testbed still requires safety certification, performance validation and reliable integration of fuel cells, storage media and balance-of-plant. The catalogue notes ongoing optimisation work and certification-oriented safety compliance as part of the current status.



7. Critical analysis of business cases

7.1. Methodology

This chapter introduces the critical analysis of the hydrogen business model cases previously described. To address the question of how these models operate and their distinguishing features, the selected cases were examined and classified within an analytical matrix structured around key variables. The purpose of this classification is to allow for a structured categorization of the different Business Models (BMs) and support the identification of a shortlist of illustrative cases.

The four main variables (or drivers) used for classification in the matrix are:

1. **Initiative drivers:** the case studies were distinguished into demand-side driven, supply-side driven, or territorial/place-based initiatives;
2. **End use / application:** this variable identifies the primary application of hydrogen, such as transport, district heating, industrial use, or other applications.
3. **Financing model:** classification is based on the main source of funding, which can be public, private, or a hybrid form such as Public-Private Partnership (PPP).
4. **Energy source for production:** this variable categorizes hydrogen based on the energy source used for its production

Below a description of each driver has been taken into consideration.

1. Initiative drivers

The "Initiative drivers" identifies the main driving force that led to the project's initiation and development. The three categories capture different strategic approaches to overcoming the challenges of hydrogen deployment:

- **Demand-side driven initiatives:** these projects are founded on securing a reliable end-user or anchor customer to mitigate market risk and guarantee long-term financial viability. The primary focus is on establishing long-term off-take contracts for the hydrogen produced, thereby justifying significant investments in production and infrastructure. Successful demand-driven cases are typically anchored by stable consumers, such as refineries, industrial clusters, or captive transport fleets (like buses or rail operations with predictable timetables). Lessons from successful demand-driven cases show that anchoring projects to stable consumers is essential for de-risking investments during early market phases;
- **Supply-side driven initiatives:** these initiatives are motivated by the desire to leverage a specific production advantage to minimize the Levelised Cost of Hydrogen (LCOH). They prioritize optimizing the energy source and utilization factor of the production assets. For instance, the hydro-powered electrolyzers in Scandinavia demonstrate this model, where co-locating units at existing hydropower plants ensures high utilization rates and predictable power supply, making the projects financially viable and leading to a lower LCOH. Evidence suggests that co-locating units at existing power plants or using by-product hydrogen from industrial processes can significantly lower CAPEX and ensure high utilization rates;

Beyond supply and demand logic, the methodology recognizes that territorial initiatives must move through a "stepwise masterplan" to evolve from isolated pilots into integrated ecosystems.

- **Territorial/place-based initiatives:** these models go beyond singular supply or demand logic by focusing on creating an integrated, geographically defined ecosystem, often referred to as a



"hydrogen hub" or "hydrogen valley". The key goal is to overcome infrastructural and demand gaps simultaneously through a systemic approach. Because they coordinate multiple steps of the hydrogen value chain (production, storage, distribution, and various end-use sectors), they typically require comprehensive methodological approaches, multi-actor coordination, and hybrid governance that aligns industrial players, public authorities, and sometimes community actors under a shared regional strategy. To succeed, these initiatives require a stepwise masterplan that moves from isolated pilots to integrated regional ecosystems, often involving a "quadruple-helix" approach to align industry, government, academia, and civil society.

2. End use / application

The variable "End use / application" classifies business models based on the primary sector or application for which the hydrogen is intended. The main applications driving business case development are **transport, district heating, industrial use, storage, or other applications.**

- **Industrial sector:** as described in the section "Overview of the role of hydrogen in the future energy market", the industrial sector currently stands out as the anchor market for hydrogen, accounting for the largest share of demand in 2030 across most scenarios and studies, largely reflecting its established role as an industrial feedstock. Hydrogen is widely regarded as a key enabler for the decarbonisation of hard-to-abate industries, including oil refining, chemical production and steel manufacturing, where it can substitute fossil-based inputs and fuels. In these sectors, hydrogen is used not only as a raw material (for example in ammonia, methanol or direct reduced iron production), but also as a source of high-temperature heat, enabling substantial reductions in greenhouse gas emissions where direct electrification is technically or economically challenging. Co-locating production within existing industrial clusters or "brownfield" sites reduces initial CAPEX and simplifies the permitting process by leveraging existing utility connections. Moreover, this sector is the primary anchor because its demand is structural and increasingly driven by regulatory pressures like the CBAM and ETS. Because industrial demand is structural and increasingly regulation-driven, positioning hydrogen valleys as industrial decarbonisation hubs provides a more robust early market than mobility alone.
- **Transport sector:** It is expected to scale up rapidly, with hydrogen deployment concentrating primarily on segments that are difficult to electrify, such as heavy-duty road transport (trucks and buses), regional rail on non-electrified lines, and maritime and port-related applications. These uses are particularly relevant in logistics hubs and port areas, where hydrogen can be supplied to captive or semi-captive fleets with high utilisation rates. Such configurations offer stable and predictable demand profiles, which are essential for de-risking investments in hydrogen production, storage and refuelling infrastructure during the early phases of market development. A key lesson is that using a "corridor logic"—placing refuelling stations every 60-100 km along TEN-T routes—builds the necessary confidence for operators to transition to heavy-duty hydrogen vehicles. Additionally, successful transport models often integrate multimodal nodes, connecting ports, interports, and logistics hubs to maximize asset utilisation.
- **Urban heating:** hydrogen production through electrolysis offers system-level efficiency gains, as electrolyzers generate low-temperature waste heat that can be recovered for on-site industrial uses or integrated into district heating networks. This heat recovery potential can enhance the overall energy efficiency, economic performance and territorial integration of hydrogen projects, further strengthening their long-term viability. Beyond simple energy supply, the methodology recognizes hydrogen as a system-level efficiency tool. By-product heat from electrolysis can be recovered for district heating or adjacent industrial processes, lifting overall system efficiency from roughly 70% to 85%. In terms of storage, hydrogen acts as a flexibility vector that can address renewable energy curtailment by providing long-duration storage and grid-balancing services.



- **Storage:** beyond industry and transport, hydrogen is also foreseen as an increasingly important vector in the power and energy system, especially for providing grid flexibility, balancing variable renewable energy sources and enabling long-duration or seasonal energy storage. While its role in electricity generation remains limited in the short term, most long-term scenarios indicate that hydrogen's contribution to the overall energy mix becomes more significant after 2040, as renewable penetration increases and system flexibility requirements grow. Furthermore, hydrogen can address renewable energy curtailment and grid constraints by acting as a long-duration energy storage vector.

Generally, hydrogen serves not just as a fuel, but as a "system-level efficiency tool". This includes the recovery of waste heat from electrolysis to reach overall system efficiency of up to 85% and the valorisation of Oxygen (O₂) as a secondary revenue stream.

3. Financing model

The "Financing model" variable determines how the hydrogen business model (BM) is capitalized and how financial risks are allocated and managed across the project's lifespan. The classification distinguishes three main archetypes:

- **Public funding:** it relies primarily on government and EU capital (grants, recovery funds, IPCEI) to de-risk early investments and cover high initial Capital Expenditures (CAPEX). This strategy is crucial before projects achieve stable revenue generation or market competitiveness. Examples include Germany's IPCEI support (over €8 billion in public funds aiming to mobilize €33 billion in private investment) and national schemes like the Carbon Contracts for Difference (CCfDs), designed to bridge the cost gap between low-carbon hydrogen and fossil fuels. Similarly, Italy utilized PNRR funds, granting €7.469 million to projects like the **Hydrogen Hub di Civitavecchia**. Combining different public streams, such as EU demo funds with national recovery funds (e.g., PNRR), can fully finance infrastructure and de-risk early commercial entry.
- **Private funding:** it involves capitalizing projects mainly through corporate capital, commercial loans, or private equity. This model is driven by long-term profitability expectations and decarbonization obligations, such as those imposed by the CBAM (Carbon Border Adjustment Mechanism), which becomes fiscal in January 1, 2026, compelling industries (steel, cement, fertilizers) to reduce embedded carbon. Purely private models require stable and structural anchor demand to be bankable. A notable example is the **MOL Green Hydrogen Refinery in Hungary**, where the €22 million project was entirely financed by MOL, anchored by the need to cut refinery CO₂ emissions. Fully corporate financing is most effective when the business case is anchored in mandatory emission reductions, allowing for large-scale projects without waiting for external offtakers
- **Hybrid funding model:**
 - **Public-Private Partnership (PPP) model:** the public-private partnership (PPP) model is a form of collaboration between public entities and private investors aimed at developing infrastructure projects and public services. This model allows for the sharing of risks and benefits by leveraging financial resources and the managerial efficiency of the private sector, while the public sector ensures regulatory compliance and serves the public interest. These examples demonstrate the success of the PPP model in facilitating the deployment of innovative technologies and the execution of impactful infrastructure projects, since PPPs bring together the best of both worlds: the stability and resources of the public sector with the efficiency, innovation, and risk management capabilities of the private sector. In Annex 9 there is a summary table with examples of projects funded through PPPs.
 - **Community-driven hydrogen project:** it is a decentralized approach to project development where local communities, cooperatives, or grassroots organizations take the



lead in financing, managing, and operating renewable energy and hydrogen initiatives. This model emphasizes local ownership, social engagement, and sustainability, ensuring that the benefits remain within the community. Community-driven models have proven to be effective in fostering **energy democracy**, strengthening local economies, and ensuring a more inclusive and sustainable transition to renewable energy solutions. Community-driven projects leverage the active involvement of users to create solutions that meet real needs. Inclusion and active participation generate trust and long-term sustainability. Specifically, community ownership through cooperatives can be a powerful vehicle for social licence and local investment, particularly in rural or transitional areas. In Annex 10 there are examples of community-driven projects, cited so far.

- **Hybrid funding models:** it combines multiple financial sources—such as public funding, private investments, and end-user revenue—to support infrastructure and energy projects. This approach balances initial capital expenditures (**CAPEX**) with operational expenses (**OPEX**), ensuring financial sustainability and reducing investment risks. Hybrid models are particularly useful for hydrogen and renewable energy projects, where large upfront investments are needed before revenue generation becomes stable. These models are flexible and well-suited for evolving markets. Hybrid funding models have proven essential in **bridging the gap between innovation and commercialization**, ensuring that hydrogen and renewable energy projects can scale effectively while minimizing financial risks. Hybrid models combine elements of the public, private, and community sectors to maximize value creation. In annex 11 there is a summary table of hybrid funding projects, cited so far.

Hybrid models that combine public, private and community-driven approaches are emerging as one of the most promising governance options for hydrogen valleys, corridors and hubs. The projects reviewed in the deliverables - from Energiegenossenschaften and eFarm in Germany to Orkney, Hvidovre, Hy2B, Mazovian Hydrogen Valley, Upper Austria Hydrogen Initiative, Hydrogen Park Porto Marghera, H2 Valle Padana, Hydrogen Hub Civitavecchia, H2iseO and others - show that no single actor group can by itself deliver the scale, legitimacy and financial robustness that hydrogen deployment requires. Instead, successful initiatives tend to create structured coalitions where regional and local authorities, industrial players, utilities, infrastructure operators, universities and, increasingly, citizens and energy communities share roles, risks and benefits. In practice, these hybrid arrangements take different forms. Some projects build formal public-private partnerships (PPP) around a specific asset or cluster (e.g. port-based hydrogen valleys, refinery decarbonisation projects, motorway corridors), with public actors setting the strategic direction and mobilising EU/national funds, while private partners provide technical know-how, project development capacity and long-term operation. Others evolve into cluster-like “valleys as platforms”, as in Mazovia, Upper Austria or Porto Marghera, where a lead industrial or regional player coordinates a network of companies, research institutions and authorities under a shared strategy and dedicated governance body. A third family is represented by community-based and cooperative models (Energiegenossenschaften, eFarm, Orkney, Hvidovre, elements of Hy2B), where citizen-owned RES, energy communities and local cooperatives become direct investors and beneficiaries, strengthening social licence and anchoring projects in the local economy. These hybrid models address several weaknesses and gaps highlighted in the SWOT and gap analysis. First, they broaden the capital base and risk-sharing capacity: public funds (grants, guarantees, recovery plans) de-risk early investments, while private and community capital support long-term operation and replication. Second, they enhance social acceptance and co-ownership, by giving municipalities, citizens and local businesses a visible role in governance and benefit-sharing, which is crucial for sensitive assets such as electrolyzers, pipelines and refuelling stations. Third, they create institutional continuity beyond individual projects: initiatives like Hydrogen Park Porto Marghera, Upper Austria Hydrogen Initiative or regional hydrogen valleys act as permanent “homes” for multiple waves of projects, rather than one-off consortia that dissolve after grant closure. Finally, by embedding community and cooperative actors into PPP structures, hybrid models help bridge the gap between territorial development objectives (jobs, skills,



just transition) and purely commercial business logics, making hydrogen deployment a more credible and enduring component of regional transformation strategies.

4. Energy source for production

Hydrogen can generally be produced using different energy sources and feedstocks, which strongly influence both its cost and environmental impact. Today, the most widespread production routes are still based on fossil fuels, particularly natural gas, through processes such as steam methane reforming (SMR) or autothermal reforming (ATR), which generate hydrogen but also significant CO₂ emissions; when CO₂ is not captured this is commonly referred to as “grey hydrogen”, while the integration of carbon capture and storage (CCS) leads to “blue hydrogen”. Coal can also be used via gasification, although this pathway is highly carbon-intensive and increasingly phased out in many regions. From a decarbonisation perspective, the most promising option is water electrolysis powered by renewable electricity from sources such as solar, wind, hydropower or geothermal energy, producing so-called “green hydrogen” with very low lifecycle emissions. Additional pathways include biomass and biogas-based processes, which can support circular economy approaches, and nuclear-based hydrogen production, where nuclear energy supplies electricity or high-temperature heat for electrolysis or thermochemical cycles, often referred to as “pink hydrogen”. Finally, several emerging technologies are under development, including methane pyrolysis, solar thermochemical processes and biological pathways, which are still largely at the research or demonstration stage. A significant lesson for production is that reusing brownfield petrochemical sites and existing gas infrastructure—such as pipelines—accelerates rollout, lowers costs, and reduces permitting barriers. While green hydrogen from renewable electrolysis is the most promising for decarbonisation, emerging pathways like methane pyrolysis or bio-based routes offer additional flexibility for circular economy approaches

Below a synthesis of the most used sources of energy:

- **Natural gas** (fossil-based; typically via SMR/ATR)
- **Coal** (fossil-based; typically via gasification)
- **Renewable electricity** (solar, wind, hydropower, geothermal; for water electrolysis)
- **Biomass / biogas / biomethane** (bio-based routes such as gasification or reforming)
- **Nuclear energy** (electricity and/or high-temperature heat for electrolysis or thermochemical cycles)
- **Methane pyrolysis energy input** (often grouped as “turquoise” routes; yields H₂ + solid carbon)
- **Solar thermochemical heat** (high-temperature solar-driven cycles; emerging)
- **Biological pathways** (microbes/algae-based; emerging)

Hereby a graphic summarizing the classification:

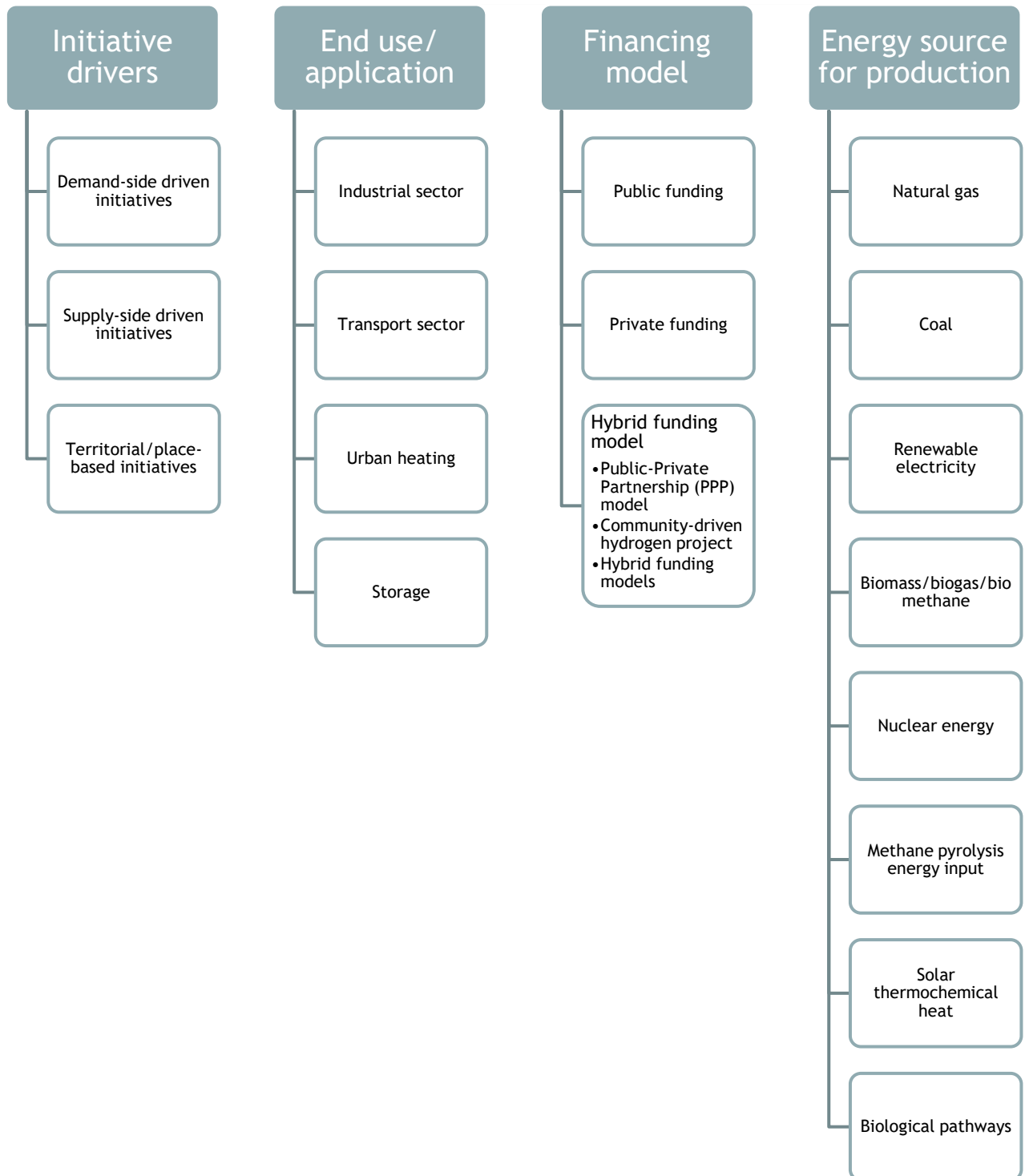


Figure 4-Methodology for Business Model

7.2. Matrix

This structured classification highlights the key characteristics that define the feasibility and strategy of hydrogen deployment in Central Europe:


- **Initiative Drivers:** the majority of successful early projects are Demand-side driven (e.g., MOL Refinery, H2iseO Rail, Brno Public Transport). This confirms that mitigating market risk by securing








a reliable anchor customer (like a captive fleet or an industrial process with structural demand) is the prerequisite for financial viability. However, large-scale projects and corridors (like NAHV or GET H2 Nukleus) are typically Territorial/Place-based initiatives, focusing on integrated ecosystems and multi-actor coordination to overcome the "chicken-and-egg problem" between supply and demand simultaneously.

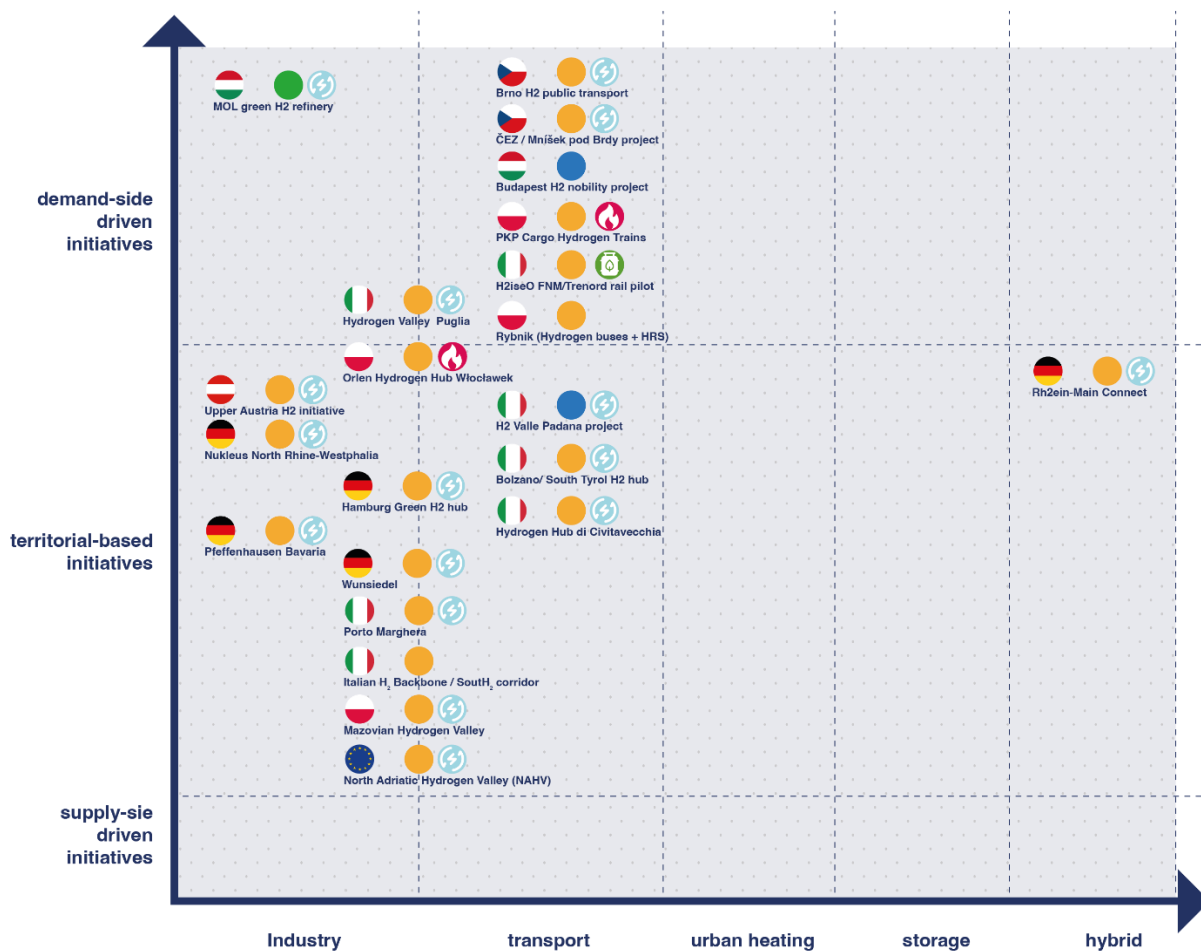
- **End Use / Application:** while long-term forecasts show transport scaling, the current anchor market is overwhelmingly the Industrial sector (e.g., refining, steel, chemicals) due to established feedstock demand and regulatory pressure from ETS/CBAM. Transport applications focus primarily on hard-to-electrify segments, specifically heavy-duty vehicles (trucks, buses) and rail on non-electrified lines (e.g., Bolzano, H2iseO, PKP Cargo).
- **Financing model:** only one major case (MOL Refinery) is purely private. Nearly all other projects rely on a Hybrid funding model, often structured as a Public-Private Partnership (PPP), leveraging EU grants (IPCEI, PNRR, CEF) to de-risk high initial Capital Expenditures (CAPEX) and mobilize private capital.
- **Energy source for production:** renewable Electricity (through electrolysis powered by RES like PV, wind, or hydro) is the declared long-term source for most projects, aligning with EU RFNBO rules and decarbonization goals. However, industrial cases also rely on Natural Gas/Industrial Gas (purified by-products or SMR) during the transition, as seen in the Orlen Hub and PKP Cargo, to ensure early supply and use existing assets

Financing model

-  Private
-  Public
-  Hybrid

Energy for production

-  Natural gas, coal
-  Renewable electricity
-  Biomass, biogas, biological path
-  Nuclear
-  Methane pyrolysis, solar thermochemical heat



Project / Case Study	Initiative Driver	End Use / Application	Financing Model	Energy Source for Production
AUSTRIA				
Upper Austria Hydrogen initiative	Territorial/place-based (Regional cluster/framework)	Industrial use (Steel, energy players)	Hybrid (Long-term programmatic funding, regional funding)	Renewable Electricity (Electrolysis)
CZECH REPUBLIC				
Brno Hydrogen public transport	Demand-side driven (City-led bus fleet transition/anchor demand)	Transport (Public transport, municipal fleets)	Hybrid (City-led cluster H2vBrno; municipal energy funding)	Renewable/Lo w-carbon (From municipal energy sources)
ČEZ / Mníšek pod Brdy project	Demand-side driven (captive public bus fleet as anchor offtaker)	Transport (regional public bus fleet)	Hybrid / PPP-type (EU/public support + regional enabling role + private delivery/investment by ČEZ ESCO)	Renewable electricity (electrolysis)
GERMANY				
GET H2 Nukleus North Rhine-	Territorial/place-based (Industrial backbone linking	Industrial use (Refinery/chemicals demand)	Hybrid (IPCEI-backed, regulated open-access network)	Renewable Electricity (Electrolysis at



Westphalia (NRW)	production and consumers) Demand-side driven (refining, chemicals, industry in the corridor)			former gas plant site)
Hamburg green hydrogen hub	Territorial/place-based (GW-class scale-first logic, industrial port cluster)	Industrial use, Transport (Port industry, mobility)	Hybrid (Public-Private collaboration, EU grant)	Renewable Electricity (Electrolysis, reusing coal plant site)
Hy2B Hydrogen Cluster (Pfeffenhausen, Bavaria)	Territorial/place-based (Regional cluster, centralized production)	Transport (Public transport buses - anchor off-taker)	Hybrid (Hybrid ownership: private companies, districts, citizen co-ops)	Renewable Electricity (Alkaline electrolysis from Bavarian RES)
Frankfurt-Rhine-Main regional hydrogen distribution network (Rh2ein-Main Connect)	Territorial/place-based (regional distribution network platform connecting multiple sectors to the H ₂ core network)	Industrial use, Transport, Urban heating (distribution infrastructure)	Hybrid (PPP-like): (consortium led, public and private funding/finance support)	Renewable Electricity (electrolysis)
Wunsiedel (WUN H ₂)	Territorial/place-based (Medium-scale regional anchor/hub)	Industrial use, Transport (Regional mobility/industry)	Hybrid (PPP municipal + private capital, programmatic support)	Renewable Electricity (PEM electrolyser from local RES)
HUNGARY				
budapest hydrogen mobility project	Demand-side driven (Early-market pilot, single HRS nucleus)	Transport (Bus mobility trials)	Public (State-led pilot)	<i>Not explicitly stated; linked to regional refinery supply</i>
MOL Green hydrogen refinery	Demand-side driven (Refinery integration/corporate climate strategy anchor)	Industrial use (Refinery processes)	Private (Entirely financed by MOL)	Renewable Electricity (10 MW PEM electrolyser inside refinery)
ITALY				
H2 Valle Padana project	Territorial/place-based (Interregional corridor/network)	Transport (Heavy road transport, logistics, interports)	Public (PNRR funding)	Renewable Electricity (RES-to-H ₂)
Hydrogen Valley in Puglia	Demand-side driven (Anchored to major industrial cluster/steel plant) Territorial/place-based	Industrial use (Steel decarbonization), Mobility	Hybrid (IPCEI-backed, SPV with industrial/finance partners; PNRR synergy)	Renewable Electricity (160-220 MW electrolysis powered by PV)
Porto Marghera	Territorial/Place-based (port-industrial hub / hydrogen valley ecosystem)	Industrial use, port/mobility and distribution	Hybrid (PPP-like) (PNRR grant and private investment/implementation)	Renewable electricity (electrolysis)



Bolzano/ South Tyrol hydrogen hub	Territorial/place-based (hydrogen hub/valley with corridor masterplan) Demand-side driven (Mobility anchor along strategic Brenner corridor)	Transport (buses, cars and trucks)	Hybrid (PPP-like): ERDF, private funding (Hydrogen Centre) and PNRR-funded expansion (Adige Valley)	Renewable electricity: electrolysis (incl. PV-fed electrolysis for Adige Valley)
H2iseO (FNM/Trenord rail pilot)	Demand-side driven (Captive rail off-take, predictable demand)	Transport (Regional rail on non-electrified lines)	Hybrid (PPP led by regional public transport group; PNRR funds)	Biomass/Biogas (Steam Reforming of biomethane with CO ₂ capture) + Renewable Electricity
Hydrogen Hub di Civitavecchia	Territorial/place-based (Port-centric hydrogen valley)	Transport (Port vehicles, short-haul logistics)	Hybrid (PPP led by Region/AdSP; EU LIFE and PNRR funding)	Renewable Electricity (AEM Electrolysis powered by off-grid PV)
Italian H₂ backbone / south₂ corridor	Territorial/place-based (corridor/backbone enabling cross-border market integration)	Industrial use and mobility	Hybrid (regulated TSO investment + EU co-funding/PCI/CEF Energy support, fast-track approvals)	<i>Not explicitly stated; linked to regional refinery supply</i>
POLAND				
Orlen hydrogen hub Włocławek	Demand-side driven (Industrial anchor, national corridor backbone) Territorial/Place-based (hub)	Industrial use (Refining substitution), Transport (Mobility corridor)	Hybrid (Industry-led PPP; EU CEF/AFIF, national recovery funds)	Natural Gas/Industrial Gas (Purification of by-product H ₂ from brine electrolysis, SMR/electrolysis mix)
PKP cargo hydrogen trains	Demand-side driven (Captive rail off-take, industrial R&D alliance)	Transport (Freight rail, shunting locomotives)	Hybrid (Industrial R&D alliance, public support needed for scale)	Natural Gas/Industrial Gas (Hydrogen from coking gas/industrial sources)
Mazovian hydrogen valley	Territorial/place-based (Valley-style orchestration/regional cluster)	Industrial use, Transport (Industry, mobility)	Hybrid (Cluster of 50+ entities, led by ORLEN; EU-funded demo projects)	Renewable Electricity and Biomass/Waste (Electrolysis and waste-to-hydrogen routes)
Rybnik (Hydrogen buses + HRS)	Demand-side driven (City-led fleet transition/public transport anchor)	Transport (Public transport, mobility)	Hybrid (Heavy reliance on grants/subsidies, municipal commitment)	<i>Not explicitly stated; likely sourced H₂ via logistics</i>



MULTI-COUNTRY / CLUSTER				
North Adriatic hydrogen valley (NAHV)	Territorial/place-based (Transnational ecosystem, 37 partners)	Industrial use, Transport (Hard-to-abate sectors, maritime/land transport)	Hybrid (Clean Hydrogen Partnership grant, national/private investment)	Renewable Electricity (Water electrolysis)

Table 1 - Matrix of business cases

7.3. Business Models' list

The matrix enabled a structured categorisation of different Business Models list, highlighting their specific characteristics and supporting the identification of a shortlist of illustrative cases, that represent the dominant strategic pathways for hydrogen implementation and market de-risking in Central European countries:

1. **Industrial decarbonization anchor model**
2. **Integrated port and logistics hub model**
3. **Transnational corridor and backbone model**
4. **Captive mobility fleet hub model**
5. **Decentralized supply and system service hub model**

The chapter reorganizes and integrates the hydrogen business models (BMs) using the **Triple Layered Business Model Canvas (TLBMC)**. This framework ensures that each model is evaluated not only for its economic viability but also for its lifecycle environmental impacts and social value.

To ensure the success and resilience of a hydrogen hub, these three layers must be consistently aligned:

- **Economic layer:** this is based on the classic Business Model Canvas and defines how an organization—or a coordinated ecosystem of actors—creates, delivers, and captures financial value. It links strategic objectives with operational processes and financial flows to provide the foundation for bankable and scalable projects. It addresses standard components such as value propositions, customer segments, revenue streams, and cost structures.
- **Environmental layer:** this layer adopts a life-cycle perspective. It quantifies the ecological impact of the project by evaluating variables such as Greenhouse Gas (GHG) emission reductions, energy use, and resource consumption (e.g., the high-water consumption required for electrolysis). In hydrogen hubs, this layer often highlights innovations like water circularity—using treated wastewater to reduce costs and preserve potable resources.
- **Social layer:** this layer is stakeholder-centric and focuses on the social value created for the community, employees, and end-users. It evaluates impacts such as the "just transition" for workers moving from fossil-fuel industries to green energy, improvements in public health due to better air quality, and the strengthening of national energy independence

Strategic role in hydrogen hubs

According to the sources, the TLBMC serves as a conceptual backbone for transitioning from isolated pilots to integrated regional ecosystems. Its role is critical for:

- **Social acceptance:** by focusing on the social layer, it helps build a "social license" to operate, involving local communities and cooperatives to ensure that the benefits of the energy transition remain within the territory.



- **Decision support:** the TLBMC informs and is complemented by cross-cutting analytical tools like Cost-Benefit Analysis (CBA) and Multi-Criteria Analysis (MCA). This ensures that project configurations are compared transparently against technical, economic, environmental, and social criteria.
- **Managing complexity:** in hydrogen hubs, the business model does not refer to a single asset but to an integrated, place-based system. The TLBMC helps define the roles and interfaces between diverse actors, such as renewable energy producers, grid operators, and industrial off-takers.

7.3.1. Industrial decarbonization anchor model

This model is designed to maximize financial viability by securing stable, structural demand from existing large-scale industrial consumers, thereby mitigating market risk, focusing on "Revenue Robustness" by anchoring demand in refineries and steel clusters where hydrogen use is a technical necessity. The model is strongly reinforced by regulatory drivers such as the EU Emissions Trading System (ETS) and the Carbon Border Adjustment Mechanism (CBAM), which increase the economic value of low-carbon production and supply chain decarbonisation.

Variable	Characteristics
Initiative driver	Demand-side driven—anchored by structural off-take contracts from major end-users.
End Use / application	Industrial Use (feedstock substitution, high-temperature heat, refining, steel).
Financing model	Private (corporate capital driven by emissions reduction obligations) or Hybrid (leveraging IPCEI/PNRR support to bridge the cost gap).
Examples	MOL Green Hydrogen Refinery (Hungary), Hydrogen Valley in Puglia (Italy, anchored to steel industry).

Table 2- Industrial decarbonization anchor model

Economic layer

- **Value proposition:** reliable and continuous supply of renewable or low-carbon hydrogen for industrial processes; reduction of carbon compliance costs (ETS and CBAM exposure); long-term price visibility; integration with industrial utilities such as water management, heat recovery and oxygen supply. Value is anchored by long-term offtake contracts from large industrial consumers. For instance, the MOL Green Hydrogen Refinery in Hungary represents a €22 million purely private investment de-risked by internal demand for feedstock substitution, producing 1,600 t/year. The Puglia Green Hydrogen Valley leverages a hybrid model with IPCEI support (€370 million) to supply a major steel cluster.
- **Customer segments:** large industrial consumers (refineries, steel plants including DRI facilities, chemical and fertiliser producers); utilities and traders seeking certified renewable hydrogen and Guarantees of Origin.
- **Key activities:** development and operation of large-scale electrolyzers; integration with existing industrial processes; advanced water treatment and recycling; management of long-term offtake contracts; certification and monitoring for renewable hydrogen compliance.
- **Key resources:** industrial-scale electrolyzers (typically 10-300 MW); dedicated or contracted renewable electricity supply (PPAs or direct connections); industrial land and grid access; water infrastructure; specialised technical workforce.



- **Revenue streams:** hydrogen sales under long-term offtake contracts; green premiums embedded in downstream industrial products; avoided ETS and CBAM costs; valorisation of by-products such as oxygen and waste heat.
- **Cost structure:** high upfront CAPEX for electrolyzers and grid connections; electricity OPEX as the dominant cost component; water treatment and reuse systems; compliance, certification and monitoring costs.

Environmental layer

- **Functional value:** tonnes of CO₂ avoided per tonne of hydrogen substituting fossil-based feedstocks or fuels. The MOL project avoids roughly 25,000 t/year. It also incorporates "water circularity," using treated wastewater to reduce costs and preserve potable resources.
- **Lifecycle impacts:** emissions largely concentrated in electrolyser manufacturing and renewable generation assets; near-zero operational emissions when supplied with renewable electricity.
- **Resource use:** high electricity demand and significant water consumption, increasingly mitigated through water circularity solutions such as the use of treated wastewater, reducing both costs and pressure on potable water resources.
- **System benefits:** deep decarbonisation of hard-to-abate industrial sectors; reduction of local air pollutants; contribution to circular resource use through by-product and water recovery.

Social layer

- **Social value:** preservation and transformation of industrial employment; support for a just transition of workers from fossil-based processes to low-carbon operations; strengthening of regional industrial competitiveness and energy independence.
- **Stakeholders:** industrial workforce, local communities, regulators, water utilities, technology providers, financial institutions.
- **Governance:** SPVs or joint ventures aligning industrial off takers, energy suppliers and public authorities, with clearly defined risk- and benefit-sharing mechanisms.
- **Net social benefit:** long-term industrial resilience, workforce upskilling and improved environmental and health conditions in industrial regions.

Success is anchored in mandatory emission reductions; purely private models, like the MOL Refinery, show that corporate financing is viable when the project is central to a long-term decarbonisation strategy. Moreover, lessons from the Puglia Green Hydrogen Valley and MOL Refinery show that these models are most effective when anchored to major industrial clusters and implemented via Special Purpose Vehicles (SPV) to mobilise private capital against mandatory emission reductions.

7.3.2. Integrated port and logistics hub model

This model leverages existing coastal or logistics nodes to create a spatially defined ecosystem (a form of Hydrogen Valley). In particular, ports serve as "transnational gateways" for the future import/export of hydrogen derivatives. It prioritizes the conversion of **brownfield industrial sites** and combines different forms of demand to achieve scale. This model relies on "demand diversity," combining maritime, port equipment and short-haul logistics to ensure the high-volume flows necessary for larger scales.

Variable	Characteristics
Initiative driver	Territorial/Place-based —focusing on coordinating multiple steps of the value chain within a specific geographic area (e.g., port hinterland).
End Use / application	Mixed Use (Transport: maritime, port equipment, short-haul logistics; Industrial Use: adjacent industry).



Financing model	Hybrid (Public-Private Partnership, leveraging national recovery funds and regional/EU grants like LIFE or PNRR to de-risk infrastructure CAPEX).
Examples	Hamburg Green Hydrogen Hub (Germany), Hydrogen Hub di Civitavecchia (Italy), Hydrogen Park - Porto Marghera (Italy).

Table 3 - Integrated port and logistics hub model

Economic layer

- **Value proposition:** multi-user hydrogen supply and logistics services within port areas; decarbonisation of maritime operations and hinterland transport; regeneration and valorisation of underused industrial land. The Hamburg Green Hydrogen Hub converts a former coal plant into a 100 MW facility targeting 10,000 t/year. Revenue is diversified across hydrogen sales, bunkering fees, and logistics services.
- **Customer segments:** shipping companies, terminal operators, logistics providers, port vehicle fleets, adjacent industrial users and port authorities.
- **Key activities:** hydrogen production via electrolysis; compression and storage; refuelling and bunkering services; integration with port energy, safety and logistics systems.
- **Revenue streams:** hydrogen sales; refuelling and bunkering fees; storage and logistics services; infrastructure-as-a-service revenues for multiple port users.
- **Cost structure:** electrolyser, compression and storage CAPEX; port infrastructure upgrades; safety and monitoring systems; O&M and compliance costs.

Environmental layer

- **Functional value:** emissions avoided per vessel call, per tonne of cargo handled or per vehicle-kilometre in port operations.
- **Lifecycle impacts:** significant reductions in SO_x, NO_x and particulate matter; limited additional land take through brownfield reuse.
- **Resource efficiency:** short distribution distances; opportunities for waste heat recovery and integration with port-area heating systems; manageable water demand.

Social layer

- **Social value:** improved air quality and public health in port cities; creation of skilled jobs in green logistics and energy services; enhanced competitiveness of European ports.
- **Stakeholders:** port workers, local residents, municipalities, port authorities, shipping and logistics operators.
- **Governance:** public-private partnerships coordinated by port authorities and aligned with long-term port development strategies.

Successful cases like Porto Marghera and Civitavecchia highlight that reusing brownfield petrochemical sites accelerates rollout and that combining diverse funding streams—such as EU demo funds (LIFE) with national recovery funds (PNRR)—is critical to de-risking early port-based infrastructure.

7.3.3. Transnational corridor and backbone model

Focused on overcoming infrastructure gaps, this model links dispersed production and demand sites across large geographical areas, often along major European transport routes (TEN-T corridors). This requires alignment among infrastructure operators (TSOs) and public authorities.



Variable	Characteristics
Initiative driver	Territorial/Place-based —systemic approach to create interoperable networks and infrastructure linkages (pipelines, H ₂ refuelling stations).
End Use / application	Primarily Transport (heavy road freight, logistics, transalpine rail) and Storage (grid flexibility).
Financing model	Hybrid (Large-scale PPPs involving TSOs and motorway operators, heavily reliant on EU infrastructure funds like PNRR, CEF, or IPCEI Hy2Infra).
Examples	North Adriatic Hydrogen Valley (NAHV, transnational), H ₂ Valle Padana Project (Italy, Brenner corridor), GET H ₂ Nukleus (Germany)

Table 4 - Transnational corridor and backbone model

Economic layer

- **Value proposition:** cost-efficient long-distance hydrogen transport; access to diversified and geographically dispersed demand clusters; infrastructure-as-a-service under regulated conditions. The Italian H₂ Backbone (South₂ Corridor) utilizes conversion for 60% of its network to connect North Africa to Central Europe.
- **Customer segments:** industrial consumers, heavy-duty mobility operators, hydrogen traders, storage operators and regional distribution networks.
- **Revenue streams:** regulated transport tariffs; capacity bookings; network and balancing services.
- **Cost structure:** pipeline conversion and selective new-build CAPEX; compression, metering and monitoring systems; regulatory compliance and cross-border coordination costs.

Environmental layer

- **Functional value:** CO₂ avoided per kilometre of freight transport or per industrial user supplied with low-carbon hydrogen.
- **Lifecycle impacts:** reduced environmental footprint through reuse of existing infrastructure corridors; construction impacts concentrated in early project phases.

Social layer

- **Social value:** strengthened European energy integration and security of supply; regional economic development along major corridors; reduced road congestion and local pollution when freight shifts to hydrogen-based solutions.
- **Governance:** strong regulatory oversight; coordination among TSOs, national authorities and EU institutions; transparent third-party access rules.

Repurposing existing natural gas pipelines is a critical business benefit, as it significantly reduces time-to-market and CAPEX compared to new builds, as it happened in GET H₂ Nukleus and H₂ Valle Padana projects. In particular, GET H₂ Nukleus demonstrates competition and overcome the "chicken-and-egg" problem. Furthermore, the North Adriatic Hydrogen Valley demonstrates that success in transnational models requires formalised cross-border governance and a "quadruple-helix" approach to align multi-country industrial and political interests. Generally, specific regulatory workarounds, such as Poland's unique classification of hydrogen pipelines to reduce administrative control obligations, can further accelerate deployment, as well as the standardisation of offtake contracts and guarantees.

7.3.4. Captive mobility fleet hub model

This model targets quick market entry and stable operation by integrating hydrogen production and refuelling with captive transport fleets that have predictable demand and fixed routes. Additionally, these hubs serve as the "nucleus" for broader corridors, later attracting heavy-duty logistics. This reduces logistics



uncertainty and improves utilization rates: co-locating production at vehicle depots minimizes distribution distances and improves service reliability, making it a "plug-and-play" model for municipal authorities.

Variable	Characteristics
Initiative driver	Demand-side driven —anchored by municipal or regional transport operators guaranteeing off-take (e.g., scheduled bus or regional rail services).
End Use / application	Transport (public transport buses, municipal fleets, regional rail on non-electrified lines).
Financing model	Hybrid (City/regional government leads, utilizing specific grants/subsidies to cover initial high vehicle/fuel costs, ensuring political backing).
Examples	H2iseO (FNM Rail Pilot, Italy), Brno Hydrogen Public Transport (Czech Republic), Hydrogen Valley di Bolzano (Italy), Rybnik (Poland).

Table 5 - Captive mobility fleet hub model

Economic layer

- **Value proposition:** reliable zero-emission fuel supply for fleets with fixed duty cycles; simplified logistics through depot-based refuelling; reduced exposure to fuel price volatility.
- **Customer segments:** public transport operators, municipalities, regional transport authorities, waste collection and municipal service fleets.
- **Revenue streams:** hydrogen supply contracts; refuelling services; revenues embedded in long-term public service contracts.
- **Cost structure:** vehicle CAPEX; refuelling infrastructure; hydrogen production or procurement; O&M and training costs. The H2iseO project in Italy replaces diesel trains with hydrogen rail, supported by a dedicated supply chain at vehicle depots to minimize distribution costs.

Environmental layer

- **Functional value:** zero tailpipe emissions per vehicle-kilometre; substantial reductions in urban air pollutants. In Rybnik, Poland, the use of "non-permanent infrastructure" helped navigate early permitting impasses for bus refuelling.
- **System benefits:** noise reduction; highly visible decarbonisation outcomes that support public acceptance and replication.

Social layer

- **Social value:** cleaner and healthier public transport systems; increased public trust and social licence for hydrogen technologies; workforce reskilling for drivers and maintenance personnel.
- **Governance:** city- or region-led PPPs with strong public-sector coordination and long-term planning horizons.

The Bolzano and H2iseO cases prove that a stepwise masterplan—moving from a single depot pilot to regional integration—is essential for building technical credibility over time. To navigate permitting impasses, a key lesson from Rybnik is the use of "non-permanent infrastructure" (not connected to the ground) for early-stage refuelling.

7.3.5. Decentralized supply and system service hub model

This model emphasizes optimizing supply-side conditions to achieve a competitive Levelised Cost of Hydrogen (LCOH). It focuses on locating electrolyzers near stable, low-cost renewable sources or utilizing waste heat for production efficiency and often involves providing flexibility services back to the electricity



grid. Financial viability is boosted by "revenue diversification," where the hub earns from hydrogen sales as well as grid flexibility and waste-heat recovery services.

Variable	Characteristics
Initiative driver	Supply-side driven—prioritizing the high utilization factor and low price of the energy source.
End Use / application	Storage and Power/Heat (grid stability, P2X, waste heat recovery for district heating).
Financing model	Hybrid (often involves energy utilities and local energy cooperatives to ensure local grid integration and social license).
Examples	Wunsiedel (WUN H2, Germany, utilizing flexibility services), ECUBES (Slovenia), Hy2B Hydrogen Cluster (Pfeffenhausen, Bavaria, Germany)

Table 6 - Decentralized supply and system service hub model

Economic layer

- **Value proposition:** competitive hydrogen production; provision of grid balancing and flexibility services; additional revenue streams from heat and oxygen.
- **Customer segments:** utilities, local industries, district heating operators, mobility fleet operators, TSOs and DSOs.
- **Revenue streams:** hydrogen sales; ancillary and flexibility services (aFRR/mFRR); heat and oxygen sales; incentive-based revenues where applicable.
- **Cost structure:** electrolyser and storage CAPEX; integration with power systems; water supply and treatment; digital control and optimisation systems.

Environmental layer

- **Functional value:** renewable electricity absorbed per kilogram of hydrogen produced; avoided curtailment of renewable generation.
- **Resource efficiency:** high overall system efficiency through sector coupling; recovery of waste heat lifting total efficiency towards 85%; moderate water consumption.

Social layer

- **Social value:** increased local energy autonomy; participation of communities and municipal utilities; retention of economic value within the territory.
- **Governance:** municipal utilities, cooperatives and hybrid PPP models that support community involvement and energy democracy. Fosters "energy democracy" through community-driven or cooperative models, such as the Hy2B Hydrogen Cluster in Bavaria, which involves citizen co-ops as owners.

Moreover, projects like Wunsiedel show that diversifying revenue through grid flexibility services and waste heat recovery for district heating makes decentralised hubs more resilient to energy price volatility. The Wunsiedel (WUN H2) plant (8.75 MW) sells waste heat and oxygen to local industry, making it resilient to energy price volatility.

By integrating the insights from the HyEfRe analytical framework with the detailed TLBMC canvases developed in the BMC document, the analysis confirms that **successful hydrogen deployment depends on the alignment of economic viability, environmental performance and social legitimacy**. Hybrid and place-based configurations that combine industrial anchors, diversified demand, public support and robust territorial governance emerge as the **most resilient pathways for scaling hydrogen ecosystems** beyond isolated pilots and towards long-term regional transformation.



8. SWOT analysis: barriers to adoption and strategies to overcome them

This chapter's primary goal is to translate the shortlist of illustrative BMs identified into an operational and strategic evaluation. The SWOT analysis is carried out on these selected Business Models to systematically assess their internal and external conditions. This involves examining four crucial dimensions:

- **Strengths:** internal advantages that can be capitalized upon (e.g., guaranteed demand from captive fleets, or leveraging existing brownfield sites)
- **Weaknesses:** internal limitations that must be addressed (e.g., high sensitivity of the Levelized Cost of Hydrogen (LCOH) to electricity prices, or concentration of revenue streams on a single customer)
- **Opportunities:** favorable external factors that can be leveraged (e.g., the enforcement of the Carbon Border Adjustment Mechanism (CBAM) boosting low-carbon hydrogen competitiveness, or alignment with major EU corridors like TEN-T)
- **Threats:** external factors that pose risks to the project's sustainability (e.g., price volatility, competition from alternative decarbonization technologies, or regulatory uncertainty)

The core output of this analysis is the clear identification of the specific barriers to adoption (Weaknesses and Threats) and the subsequent delineation of practical strategies required to overcome these challenges, ensuring that deployment is feasible.

Below a SWOT analysis made for each Business Model selected.

1. Industrial decarbonization anchor model

This model is typically Demand-side driven and anchored to large, stable off-takers in hard-to-abate industries like refining, steel, or chemicals.

Strengths (S)	Weaknesses (W)
Guaranteed demand: structural demand anchored by established industrial processes significantly de-risks the market and supports long-term off-take contracts.	High energy sensitivity: the levelized cost of hydrogen (lcoh) is highly sensitive to renewable electricity prices, which dominate the total cost structure.
Regulatory alignment: driven by structural regulatory pressures (e.g., cbam and ets obligations), which compel corporate investments in decarbonization, ensuring project motivation is robust,	limited diversification: revenue streams are often concentrated around a single customer or use case, creating vulnerability to industrial process changes or shutdowns.
Leverages existing assets: production sites are often co-located at existing industrial parks or refineries (brownfield), which reduces capex, minimizes permitting complexity, and leverages existing utility connections.	Supply chain risk: reliance on specific industrial components for production and integration can expose the project to supply chain vulnerabilities.
Opportunities (O)	Threats (T)
Compliance and value creation: CBAM enforcement strengthens the business case by pricing embedded carbon in fossil-based imports,	Alternative decarbonization: competition from alternative abatement technologies (e.g., direct electrification, CCUS for gas) in certain industrial



making low-carbon hydrogen derivatives more competitive in EU markets.	segments where hydrogen does not offer a decisive technical advantage.
infrastructure integration: potential to connect early industrial hubs to emerging national hydrogen backbones and corridors (e.g., GET H2, Snam’s backbone), enabling future scale-up and supply source diversification.	Regulatory uncertainty: unclear or evolving sustainability standards (e.g., RFNBO rules, Guarantees of Origin) can complicate long-term contract design.
System efficiency: valorization of waste heat generated by electrolyzers for use in adjacent industrial processes, enhancing overall system efficiency and reducing OPEX.	Volatile electricity prices: unpredictable power price volatility can erode the project’s financial viability, despite efforts to secure low-cost renewable power purchase agreements.
Integration into Smart Specialisation agendas and regional climate plans to link them to broader economic development policies	

Table 7 - SWOT Industrial decarbonization anchor model

2. Integrated port and logistics hub model

This territorial/place-based model focuses on key logistics nodes, combining mixed demand from port operations, shipping, and adjacent industry.

Strengths (S)		Weaknesses (W)	
Demand diversity: combining industrial, maritime, and land transport demand creates resilience against fluctuations in a single sector, improving asset utilization.		Operational complexity: managing heterogeneous end-use applications (e.g., fueling a ship vs. supplying a refinery) adds logistical and technical complexity.	
Strategic location: ports act as critical hubs, leveraging high-volume logistics flows along major TEN-T routes, which secures long-term relevance and scale-up potential.		Multi-Agency governance: coordination challenges due to the involvement of multiple public entities (Port Authority, municipality, regional government) and private partners, which can slow permitting and increase complexity.	
Asset reuse: high potential for reusing brownfield industrial sites (e.g., former coal plant locations) and existing port infrastructure, accelerating time-to-market and reducing CAPEX.		Initial logistics costs: until dedicated port pipelines are built, the reliance on trailer or truck logistics for local distribution adds considerable cost and operational complexity.	
Opportunities (O)		Threats (T)	
Mandated decarbonization: strong future regulatory drivers from sectors like shipping (FuelEU Maritime) and heavy-duty transport (AFIR) create non-optional demand for hydrogen.		Competition from alternatives: significant competition in the maritime sector from alternative low-carbon fuels (e.g., methanol or ammonia), especially for deep-sea shipping.	
Transnational gateway role: opportunity to position the hub as a critical trade point for the import and export of hydrogen and its derivatives, reinforcing energy security.		Permitting delays & safety: high visibility in urban/coastal areas makes projects vulnerable to public opposition and safety concerns if not	



	proactively managed, potentially leading to significant permitting delays.
Blended finance model: the structured public-private partnership (ppp) model is well-suited to accessing complex funding mixes, including eu programs (pnrr, LIFE, CEF) for de-risking infrastructure.	Infrastructure gaps: the absence of a developed hydrogen distribution network within the port's hinterland is a significant initial barrier to widespread adoption.

Table 8 - SWOT Integrated port and logistics hub model

3. Transnational corridor and backbone model

This Territorial/Place-based model focuses on developing large-scale, interoperable infrastructure (pipelines, logistics networks) to link production and demand across regions and borders.

Strengths (S)	Weaknesses (W)
Systemic scale and scope: overcomes the chicken-and-egg problem by linking dispersed production and demand, creating the necessary market liquidity for heavy transport and industrial users.	Cross-Border coordination: requires complex, formalized transnational governance and coordination among multiple TSOs, regulators, and over 37 partners (in the case of NAHV), inherently slowing down the decision-making process.
Infrastructure acceleration: repurposing existing natural gas pipelines significantly reduces the time-to-market and CAPEX compared to entirely new builds.	Lack of regulatory harmonization: divergent national regulations concerning tariffs, pipeline access, Guarantees of Origin, and safety standards impede the seamless operation of a cohesive cross-border market,.
High strategic relevance: strong alignment with major EU policy initiatives (TEN-T, IPCEI Hy2Infra), ensuring access to necessary political and financial support for large-scale investment.	High upfront costs: despite pipeline repurposing, large-scale infrastructure requires substantial, long-term CAPEX, and projects often struggle with the weak articulation of post-subsidy revenue models.
Opportunities (O)	Threats (T)
TEN-T decarbonization: directly supports the decarbonization of critical European road and rail corridors, fulfilling mandated deployment targets for heavy-duty refuelling infrastructure.	Regulatory risk for backbones: uncertain long-term regulatory frameworks for pipeline access and tariff setting (regulated open access vs. closed networks) complicates financial modelling.
Energy resilience: enhances energy security by enabling the cross-border import and exchange of hydrogen between regions with differing supply surpluses and deficits.	Pilot trap risk: due to high costs and risks, there is a threat of projects becoming stuck in the lengthy planning and study phases (policy roadmaps) without achieving Final Investment Decision (FID).
Technology standardization: drives the need for standardized technical specifications and certification schemes across borders, simplifying future replication and reducing transaction costs.	Competition from rail electrification: hydrogen rail may face competition from electrification or high-capacity battery solutions on some main corridors, although it remains critical for non-electrified routes.
Promotion of interregional partnership: pool investments and develop common KPI frameworks and digital monitoring tools for evidence-based scaling.	

Table 9 - SWOT Transnational corridor and backbone model



4. Captive mobility fleet hub model

This Demand-side driven model targets stable operations by integrating production with predictable off-takers, primarily public transport and regional rail fleets

Strengths (S)	Weaknesses (W)
High demand predictability: fixed schedules (buses, rail) and captive fleets guarantee stable off-take, minimizing utilization risk for the Refueling Station (HRS) and electrolyser.	Reliance on operating subsidies: the model often requires political backing to cover higher operational costs (OPEX), particularly the initial high price of hydrogen fuel compared to conventional alternatives.
Logistics efficiency: co-location of production/HRS at vehicle depots minimizes distribution distance, reducing logistics costs and improving service reliability (e.g., Bolzano, H2iseO).	Direct competition: faces strong competition from Battery Electric Vehicles (BEVs), especially in urban transport and short-haul logistics, where hydrogen may not offer sufficient added value.
Social license: highly visible deployment in public transport quickly builds strong public acceptance and political support for hydrogen technology.	Scaling limitations: demand is capped by the size of the captive fleet, which limits the ability to rapidly scale production capacity without branching into the industrial or heavy transport sectors.
Opportunities (O)	Threats (T)
Replicability: the model is highly transferable and modular, providing a clear blueprint for other cities and regions seeking to decarbonize their municipal or regional transport fleets.	Funding continuity risk: projects are heavily dependent on specific, time-limited public grants (e.g., for vehicle purchase or HRS deployment); a lapse in funding can halt expansion.
Corridor nucleus: successfully operated captive hubs can serve as the initial nucleus for broader hydrogen corridors, attracting subsequent heavy-duty truck and logistics demand.	Infrastructure bottleneck: the primary physical barrier remains the lack of widespread H ₂ refuelling infrastructure outside the immediate hub area, impeding flexible fleet operation.
Municipal leadership: city-led initiatives facilitate streamlined local permitting and leverage municipal utilities for secure energy and water supply.	Technological risk: integrating rolling stock renewal with dedicated production and refuelling infrastructure requires high coordination, which can lead to complex technology integration risks.

Table 10 - SWOT Captive mobility fleet hub model

5. Decentralized supply and system service hub model

This supply-side driven model leverages high-quality or constrained renewable energy sources for high utilization and prioritizes revenue diversification through power/grid services.

Strengths (S)	Weaknesses (W)
LCOH optimization: high utilization factors achieved by co-locating with stable renewables (e.g., hydro or constrained RES) directly minimize the dominant cost driver (electricity cost).	Geographic constraints: highly dependent on specific geographical advantages (low-cost hydro, high wind curtailment) which severely limits the transferability of the exact business case to other regions.
Revenue diversification: ability to earn revenue from flexibility services, ancillary grid services, and waste heat recovery (e.g., district heating),	Logistical penalty: optimal production sites may be distant from large industrial or mobility demand,



mitigating risk associated with hydrogen sales price volatility.	incurring high OPEX for transport (trucking) and compression costs.
Energy system integration: provides critical grid stability and flexibility by acting as a sink for surplus renewable energy, alleviating curtailment and supporting the broader energy transition.	Regulatory clarity needed: the commercial mechanisms for valuing and monetizing grid services (aFRR/mFRR) and waste heat are still complex and lack standardization, complicating financial projections.
Opportunities (O)	Threats (T)
Advanced technology: ideal for piloting high-efficiency technologies like Solid Oxide Electrolysis Cells (SOEC), which benefit from access to heat sources (e.g., industrial or waste heat).	Market structure risk: volatility in wholesale electricity prices can impact LCOH, even with favorable generation access, and long-term viability is dependent on stable energy market design.
Monetizing co-benefits: future policy alignment is expected to create mechanisms (e.g., flexibility markets, air-quality credits) that allow projects to fully capture and monetize their systemic value.	Grid connection lead times: securing necessary grid connection permits and infrastructure build-out lead times can be complex and delay the project timeline significantly.
Replicable utility model: provides a standardized, utility-driven blueprint (e.g., PPP with municipal utilities) for deploying small-to-medium regional anchors.	Social acceptance: new energy assets, even if clean, may face local opposition (NIMBY) and require robust community engagement strategies.

Table 11 - SWOT Decentralized supply and system service hub model

Generally, to transition from a project-based economy to a structural market, three cross-cutting gaps must be closed:

1. **Standardisation:** the prevalence of "bespoke" project-specific models increases transaction costs; standardising contracts and network access is vital;
2. **Institutional Capacity:** long-term viability requires stable institutional capacity (operators, regulators, and technicians) that outlives individual project budgets;
3. **Spatial Planning:** hydrogen business models must be anchored in comprehensive territorial strategies rather than being purely project-driven to avoid suboptimal siting and limited scalability.



9. Roadmap for implementation

The following roadmap will translate the critical analysis of business models into a concrete action plan outlining the key steps required for implementation. This roadmap is primarily anchored in the structure of a standard Business Plan (BP). To ensure that implementation choices are robust and support long-term sustainability, the roadmap is complemented by cross-cutting analytical components. These components include the Cost-Benefit Analysis (CBA), Multi-Criteria Analysis (MCA), Life Cycle Assessment (LCA) which are essential tools used to support decision-making. The analysis provided by these tools helps identify the most suitable options in terms of overall benefits (economic, social, and environmental), thereby guiding pilot actions and future investments towards scalability and long-term viability of hydrogen solutions.

9.1. Steps of implementation: Business Plan

The roadmap for implementation is structured into sequential phases that translate the hydrogen hub Business Model into an operational Business Plan. Each phase has specific objectives, deliverables and decision gates, and together they provide a structured path from initial concept to full-scale operation and replication.



Figure 5 - Roadmap



The implementation follows a series of key steps, complemented by essential analytical tools:

- **Phase 1 - Context and baseline assessment:** This phase focuses on understanding the territorial, regulatory and market context of the prospective hub. It includes:
 - Mapping of existing and planned energy infrastructure (electricity, gas, heat, transport, industrial facilities).
 - Review of relevant policy and regulatory frameworks at EU, national and regional level, including support schemes and planning constraints.
 - Baseline assessment of current energy demand, emissions profile and key industrial and mobility clusters in the region.
- The main output is a context report that frames opportunities and constraints for hydrogen deployment and informs the following phases

Phase 2 - systemic mapping and stakeholder engagement: aim of this phase is to create a functional map of the hydrogen ecosystem

- Systems thinking: conceptual maps are drawn to visualize the interactions and intensity of flows between actors (producers, grid operators, off-takers). Key step to be followed are:
 - Start from real projects (best practices / hydrogen valleys).
 - Draw conceptual maps of actors and flows (who interacts with whom, for what, with which influence).
 - Generalise into a “generic” model of a hydrogen ecosystem (key stakeholder groups + direction & intensity of interactions).
 - Use the model to discuss governance, risks, leverage points.
- Structured mapping: using a “Common questionnaire and scoring grid,” stakeholders are quantified based on their influence, interests, and attitude (supportive vs. oppositional). In this phase, to operationalise the map, we propose a **RACI matrix** for the key transferability tasks (context analysis, adaptation, pilot, monitoring, communication). A RACI matrix clarifies who is: Responsible, Accountable, Consulted, Informed. Please see Annex 12 for a deeper insight. Where useful, the RACI is complemented by engagement agreements:
 - MoUs with key institutions (e.g. region, TSO, port authority, large off-taker);
 - Letters of support from municipalities or industrial clusters;
 - Partnership agreements with community/cooperative initiatives in community-driven models.
- Typology classification: stakeholders are categorized into Core players (essential for implementation), Supporters (to mobilize acceptance), and Potential blockers (requiring targeted mitigation). A useful tool at this purpose is the influence-importance matrix, built using the evaluations of 71 experts across eight CE countries (HyEfRe survey). It classifies stakeholders according to:
 - Estimated influence (1very low; 4very high)
 - Estimated importance / interest (1very low; 4very high)

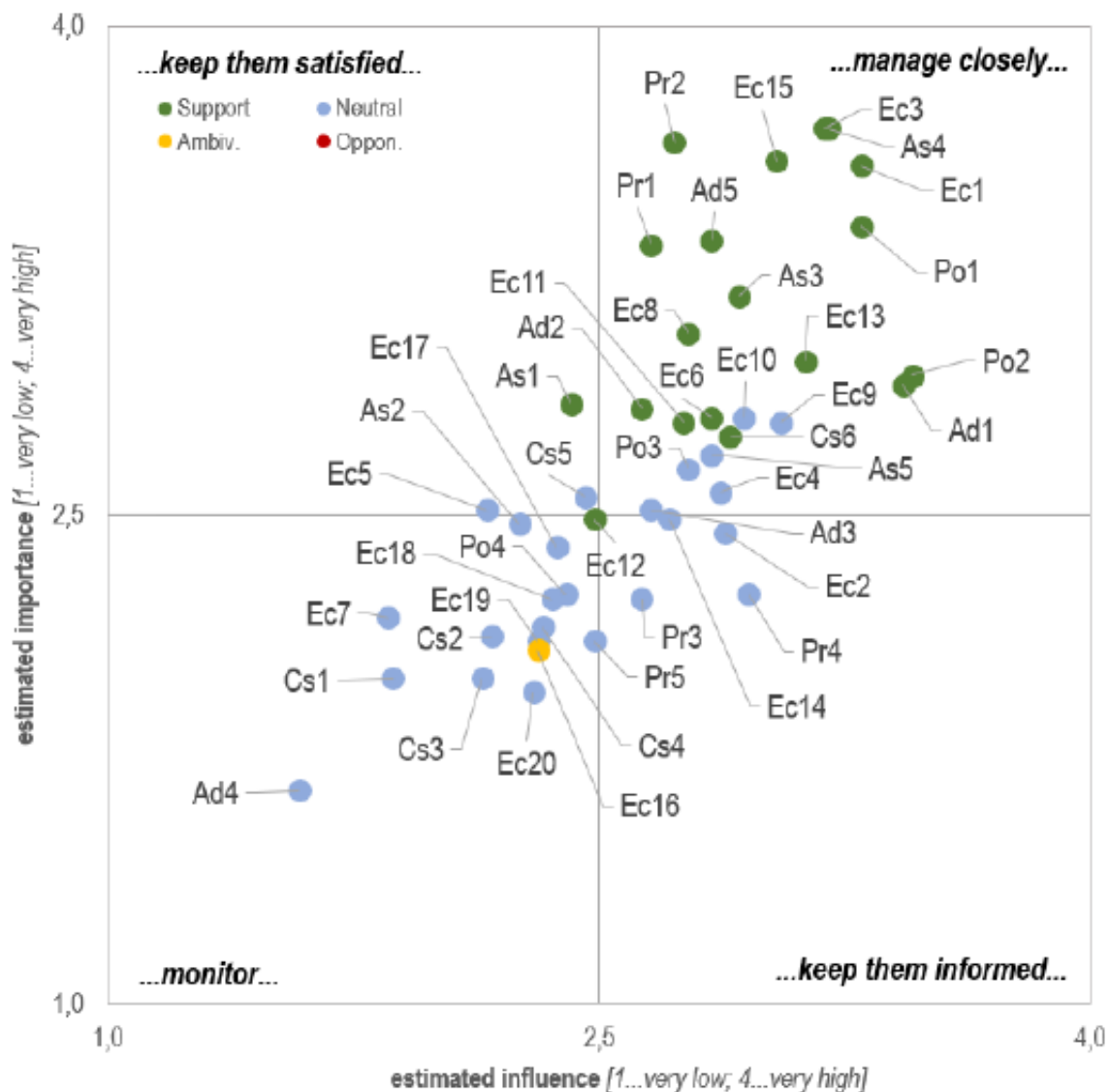


Figure 6 - Attitude of stakeholders per category towards the establishment of green hydrogen ecosystems (n=71) from HyEfRe Partnership. (2024). Activity 3.1 Stakeholder analysis

This matrix is the visual backbone for prioritising “who, why and how to involve”. It allows teams to segment all relevant actors into four engagement categories:

1. Manage closely: High influence + high importance → These are decisive stakeholders for hydrogen ecosystems.

It includes actors shape regulation, permitting, infrastructure connections, anchor demand and investment flows, such as:

- Hydrogen and derivatives producers (Ec15, Ec8, Ec10)
- Renewable energy developers (As3, As4)
- National hydrogen associations (Pr2)
- Key policy-makers (Po1, Po2, Po3)
- TSOs/DSOs and major infrastructure operators



2. Keep them satisfied: Low influence + high importance → Supportive actors who benefit from regular but not intensive engagement.

These actors strengthen local legitimacy and facilitate coordination but do not need constant involvement:

- Local business groups
- Certain academic or policy intermediaries (Ec11, Ec17)
- Municipal technical departments with high interest but limited influence

3. Keep them informed: High influence + low importance → Actors who may not be directly involved but whose support (or non-opposition) is important.

These actors are dangerous as they quickly become blockers if not informed properly, especially where hydrogen intersects with land-use or infrastructure policies.

- Stakeholders with political or industry influence but marginal direct interest in hydrogen (Pr3, Ec14, Ec2)

4. Monitor: Low influence + low importance → Minimal engagement but continuous observation for potential shifts.

These actor's position might shift as hydrogen markets mature:

- Actors with little relevance or indirect relevance (Ad4, Cs1, Cs3)
- Fossil technology suppliers who currently play a limited role

Category from Matrix	Who	Why	How
Manage closely	Ministries, agencies, TSOs, DSOs, industrial off-takers, hydrogen producers, major city/regional authorities	They shape system design, funding, regulation and market uptake	Bilateral consultations, co-design workshops, steering committees, scenario modelling
Keep satisfied	SMEs, training institutions, local business associations, supportive municipal departments	They help widen acceptance and contribute to local economic development	Targeted roundtables, updates, limited involvement in design
Keep informed	Cross-sector regulators, national bodies, transport operators, chambers	They hold veto or amplifier power even if interest is lower	Newsletters, technical briefings, open data dashboards, periodic consultations
Monitor	Groups with limited impact (e.g. fossil suppliers' pre-transition), distant NGOs	To capture any shift in interest or influence	Light-touch monitoring; public information channels

Table 12 - Stakeholder engagement map

In Annex 13 you can find a checklist, in order to understand which stakeholder is better to prioritise.

Phase 3 - Demand, supply and infrastructure concept



Phase 3 develops an integrated concept that aligns potential hydrogen demand with feasible supply options and enabling infrastructure. This includes:

- Quantification of potential hydrogen demand by sector and time horizon, using demand scenarios and sectoral projections (linked to Annexes 2-6).
- Identification and preliminary sizing of production options (electrolysis, low-carbon routes), storage and transport infrastructure, taking into account technology maturity and site characteristics.
- High-level network and logistics concept (production sites, pipeline routes, refuelling stations, industrial connections, port interfaces).

The result is a coherent concept note summarising the preferred hub configuration and its main technical and spatial characteristics

Phase 4 - Business Model design and financial structuring

In Phase 4, the preliminary concept is transformed into a structured Business Model consistent with the archetypes and hub-specific dimensions described in Chapter 4. Key activities include:

- Definition of the detailed value proposition for each core use case (e.g. industrial decarbonisation, captive fleets, port operations), specifying service bundles (hydrogen supply, logistics, flexibility, certification).
- Segmentation of offtakers and tariff/price strategies, including indicative price ranges, indexation mechanisms and potential green premiums.
- Selection and combination of BM archetypes (infrastructure-as-a-service, long-term offtake agreements, PPP/hybrid funding, merchant components) appropriate for each project phase and asset class.
- High-level financial structuring: identification of CAPEX and OPEX envelopes, funding sources (EU/national grants, loans, equity, guarantees), and preliminary allocation of investment and risk among public, private and community actors.

The outputs of Phase 4 are a detailed BM description and a preliminary financial structure that provide the backbone for the Business Plan and for subsequent CBA/MCA analyses.

Phase 5 - Techno-economic analysis and risk assessment

Phase 5 deepens the quantitative assessment of the proposed configuration, using the cross-cutting analytical tools (CBA, MCA, LCA) and risk templates presented in the annexes. The main components are:

- Techno-economic modelling of the selected configuration, including sizing of key assets, operating profiles and calculation of Levelised Cost of Hydrogen (LCOH) and other key performance indicators.
- Cost-Benefit Analysis (CBA) to monetise costs and benefits over the project lifetime, covering both financial and socio-economic dimensions (e.g. avoided emissions, health and regional development effects), using templates and indicators in Annex 21.
- Multi-Criteria Analysis (MCA) to compare alternative options (e.g. siting, phasing, production mix, infrastructure layouts) against a set of technical, economic, environmental and social criteria, as described in Annex 22.



- Initial Life Cycle Assessment (LCA) to quantify climate and environmental impacts of the preferred option and check alignment with decarbonisation targets and taxonomy/green investment criteria (Annex 23).
- Structured risk analysis using the Risk-Impact template and, where relevant, HAZID/HAZOP approaches to identify major technical, safety, regulatory and market risks and define mitigation measures.

The consolidated results feed into the Business Plan, providing an evidence base for investment decisions and for dialogue with financiers and public authorities.

Phase 6 - Detailed Business Plan and implementation roadmap

Phase 6 compiles all previous work into an integrated Business Plan and a time-bound implementation roadmap. Typical elements of this phase are:

- Consolidation of the narrative Business Plan, including: project rationale and objectives; description of the hub configuration; market analysis; BM and governance model; organisational structure; risk and mitigation strategy.
- Detailed investment and financing plan, specifying phasing of CAPEX, operating cost projections, financing instruments, expected revenues and key financial indicators (NPV, IRR, payback period), informed by CBA and MCA outcomes.
- Phased implementation roadmap with milestones, decision gates and responsibilities, covering:
 - preparatory activities (permitting, detailed engineering, procurement strategy);
 - construction and commissioning of production and infrastructure assets;
 - ramp-up of operations and progressive connection of additional offtakers and services;
 - replication and scaling to additional sites or sectors, where relevant.
- Integration of monitoring and evaluation frameworks (KPIs for technical performance, financial performance, environmental impact and social acceptance) to track implementation and enable adaptive management.

The deliverable of Phase 6 is a bankable Business Plan and an operational roadmap that can be used for funding applications, internal approvals and partnership agreements.

Phase 7 - Pilot implementation and performance validation

Phase 7 focuses on the implementation of pilot or early-stage assets and services, in order to validate the Business Model and generate operational evidence.

- Engineering, procurement and construction of pilot-scale plants and infrastructure.
- Operational integration of the solution in the specific environment (port, industrial site, city district).
- Commissioning, performance monitoring and KPI evaluation (technical, economic and impact indicators), creating a robust knowledge base for optimisation and scaling.

Phase 8 - Communication, market development and scaling



The final phase ensures that the hub achieves market penetration, stakeholder buy-in and replicability.

- Definition of brand identity and strategic positioning of the hub within the regional and Central European hydrogen ecosystem.
- Targeted communication and engagement strategies for key stakeholder groups (policy makers, industry, citizens and communities, financial institutions), using dedicated tools such as communication sheets in the implementation toolkit.
- Progressive expansion of the customer base and of the service portfolio, leveraging pilot results to secure additional offtake, investments and policy support.

The output is Communication and marketing development plan.

Through these eight phases, the roadmap operationalises the hydrogen hub Business Model into a structured, evidence-based Business Plan, suitable for decision-making, funding mobilisation and long-term implementation.

Phase	Title	Main objectives	Key activities / elements	Main outputs / deliverables
1	Context and baseline assessment	Understand territorial, regulatory and market context of the hub	1) Mapping of existing/planned infrastructure; 2) review of EU/national/regional policies and support schemes; 3)baseline of energy demand, emissions and key industrial/mobility clusters.	Context and baseline report framing opportunities and constraints.
2	Stakeholder mapping and governance set-up	Identify/prioritise stakeholders and define hub governance	1) Stakeholder identification and prioritisation; 2) use of mapping, checklist and RACI tools; 3)definition of steering structures, working groups and project office roles.	Governance framework and stakeholder map with roles and responsibilities.
3	Demand, supply and infrastructure concept	Align potential hydrogen demand with feasible supply and infrastructure configuration	1) Quantification of hydrogen demand by sector and time; 2)preliminary sizing of production, storage and transport; 3) high-level network/logistics concept for the hub area.	Integrated hub concept note (preferred configuration and spatial/technical characteristics).
4	Business Model design and financial structuring	Translate concept into structured BM and preliminary financial model	1) Definition of value propositions; 2) customer segmentation and price/tariff strategies; 3)selection/combination of BM archetypes; 4) high-level CAPEX/OPEX and funding mix;	Detailed BM description and preliminary financial structure to support the Business Plan.



			5) allocation of investments and risks.	
5	Techno-economic analysis and risk assessment	Quantify performance, costs, benefits and risks of the selected configuration	<ul style="list-style-type: none"> 1) Techno-economic modelling and LCOH; 2) CBA for financial and socio-economic impacts; 3) MCA to compare alternatives; 4) initial LCA; 5) structured risk analysis using Risk-Impact, HAZID/HAZOP where relevant. 	Consolidated analytical results (CBA/MCA/LCA and risk assessment) feeding the Business Plan.
6	Detailed Business Plan and implementation roadmap	Compile integrated Business Plan and phased implementation strategy	<ul style="list-style-type: none"> 1) Drafting of narrative Business Plan; 2) detailed investment and financing plans; 3) phased implementation roadmap with milestones and decision gates; 4) monitoring and evaluation framework with KPIs. 	Bankable Business Plan and time-bound implementation roadmap.
7	Pilot implementation and performance validation	Implement and validate pilot assets and services in real operating conditions	<ul style="list-style-type: none"> 1) EPC of pilot plants/infrastructure; 2) operational integration in port/industrial/urban environment; 3) commissioning and KPI monitoring (technical, economic, environmental, acceptance). 	Operational pilots and performance evidence to optimise and de-risk scale-up.
8	Communication, market development and scaling	Ensure social acceptance, market penetration and preparation for scaling and replication	<ul style="list-style-type: none"> 1) Brand and positioning of the hub; 2) targeted communication and engagement; 3) use of communication monitoring tools; 4) expansion of customer base and service portfolio leveraging pilot results. 	Communication and market development plan, expanded customer/partner base and conditions for scaling.



9.2. Cross-cutting components

The Cross-Cutting Analytical Components—namely the Cost-Benefit Analysis (CBA), the Multi-Criteria Analysis (MCA), and the Life Cycle Assessment (LCA)—form the methodological backbone of the Roadmap for implementation (Chapter 8.1). These analytical tools are fundamental for structuring complex decision-making processes, as they are specifically designed to guarantee that selected project options maximize overall benefits across economic, social, and environmental dimensions. The combined use of these components ensures that implementation choices are technically sound, financially quantified, environmentally robust, and socio-economically justified.

- **Cost-Benefit Analysis (CBA):** CBA is widely used tool for assessing the cost-effectiveness and broader socio-economic justification of a project over its lifetime. CBA is crucial for quantifying financial and environmental impacts, allowing project planners to compare costs with monetized benefits. Critically, CBA captures and monetizes positive externalities, such as air quality improvements, health benefits, and regional development effects. For large infrastructure investments, particularly those seeking major public funding (e.g., CEF-type initiatives), CBA provides essential economic justification using key indicators like the Net Present Value (NPV) and the Benefit-Cost Ratio (BCR). Sharing these CBA data with stakeholders (businesses, public institutions, communities) is also seen as a solution to foster consensus and support for the project. Please see Annex 21 for a CBA Template.
- **Multi-Criteria Analysis (MCA):** the MCA is defined as a critical decision-making tool used to evaluate alternatives against multiple criteria, including environmental, economic, and social factors. Its core function is to reduce the complexity of decisions, especially those involving competing interests or trade-offs between different criteria. The MCA is particularly central (Core) for policy, governance, and planning projects, as it provides an objective assessment and aids in balancing multiple objectives, such as reducing emissions while improving cost-efficiency. The MCA methodology supports transparent comparison by evaluating options against criteria such as Capital Expenditures (CAPEX), Operational Expenditures (OPEX), Levelised Cost of Hydrogen (LCOH), system reliability, GHG intensity, public acceptance, and permitting complexity. See Annex 22 for the MCA Template.
- **Life Cycle Assessment (LCA):** the LCA methodology is used to quantify the climate and environmental impacts of a project. It evaluates Greenhouse Gas (GHG) emissions per kilogram of hydrogen, energy use, and resource consumption across the full life cycle (e.g., cradle-to-gate or well-to-wheel). LCA is essential for demonstrating the reduction of GHG emissions compared to fossil fuel baselines and confirming alignment with corporate climate targets and green investment criteria. Please refer to Annex 23 for the LCA Template.

By leveraging the CBA and MCA, decision-makers gain the ability to transparently compare different technical options or configurations of hydrogen hubs, such as choosing between on-site or centralized production or alternative phasing strategies. Their combined methodology ensures that the chosen development pathways and replication strategies are grounded in technical robustness, economic viability, environmental integrity, and socio-economic acceptance.



10. Conclusions

The critical analysis of diverse business cases across eight CE countries reveals that there is no single "optimal" model; rather, success depends on aligning specific regional drivers with technical and financial configurations. The report identified five illustrative Business Models (BMs) that represent the dominant strategic pathways currently de-risking the market:

- **Industrial decarbonization anchor model:** focuses on securing stable, structural demand from large-scale consumers like refineries and steel clusters to ensure revenue robustness.
- **Integrated port and logistics hub model:** leverages existing nodes and brownfield sites to create spatially defined ecosystems with diversified demand from maritime and land transport.
- **Transnational corridor and backbone model:** addresses the "chicken-and-egg" problem by linking dispersed production and demand through large-scale, interoperable infrastructure.
- **Captive mobility fleet hub model:** targets quick market entry by integrating production with predictable municipal or regional transport demand.
- **Decentralized supply and system service hub model:** prioritizes supply-side efficiency and revenue diversification through grid flexibility and waste-heat recovery.

A key finding of this report is the prevalence and necessity of the Hybrid Funding Model. Because high initial CAPEX and the volatility of renewable electricity prices remain significant barriers, Public-Private Partnerships (PPPs) and community-driven initiatives are essential. These collaborative structures allow for the sharing of risks and benefits, mobilizing private capital through the strategic use of EU and national grants.

To overcome the identified barriers—including regulatory uncertainty and infrastructure gaps—project developers and public authorities must move beyond isolated pilots toward territorial/place-based initiatives. The roadmap for implementation presented in Chapter 9 provides the necessary framework for this transition, integrating standard Business Plan elements with cross-cutting analytical components:

- **Cost-Benefit Analysis (CBA):** to monetize socio-economic externalities and justify public investment.
- **Multi-Criteria Analysis (MCA):** to balance competing interests and technical trade-offs.
- **Life Cycle Assessment (LCA):** to guarantee alignment with decarbonization targets and green investment criteria.

In conclusion, the successful deployment of hydrogen in Central Europe requires a systemic approach that combines technical robustness with institutional continuity and social acceptance. By utilizing the tools, matrices, and roadmaps established in this report, stakeholders can foster an investment-friendly environment, ultimately ensuring that hydrogen becomes a robust and enduring component of regional transformation strategies.



11. ANNEXES

11.1. Annex 1: technology maturity map

Value-chain stage	Technology	Maturity	Deployment status / examples (per text)	Key gaps & needs called out in the text	Notes / integrations mentioned
Production	Water electrolysis (general)	Early commercial	Demo projects connected to electricity and gas grids underway; not yet in widespread commercial use in key industries & transport	Need harmonised testing protocols, common measures for performance, durability, degradation, efficiency; clearer view of costs and best-fit use cases; low-cost stack scale-up; BOS water/DEM; standardised lifetime tests.	Identified in Net-Zero Industry Act; enables renewable integration and grid services (e.g., load response)
Production	SOEC (solid oxide electrolysis)	Demonstration → Early commercial	High-temperature electrolysis; can use waste heat	Same protocol/measurement needs as electrolysis; operating-condition comparability	highest theoretical efficiency; not yet bankable at scale.
Production	SMR / reforming	Established commercial	Widely used for H ₂ (also coal gasification context)	High methane intensity	Can be combined with thermochemical/waste-heat concepts for efficiency
Production	Thermochemical cycles fuelled by waste heat	Early commercial	Use residual/waste heat from industry/power to drive H ₂ -producing cycles	High-temperature/chemically aggressive environments → corrosion, sealing, and long-term stability of reactors, heat exchangers, and sorbents.	Often integrated with reforming or broader systems to recover heat and raise system efficiency
Production	Ammonia cracking (NH ₃ →H ₂) with waste-heat recovery	Industrial/process H ₂ (recuperative preheat): established Fuel-cell-grade/distribu	Uses heat exchangers to pre-heat NH ₃ by recovering waste heat	Efficiency improvements via heat recovery	Positioned as a more circular, energy-efficient route to H ₂ from NH ₃



		ted: pilot/demonstration	from hot exhaust		
		Maritime/onboard: early demo			
Transport	Hydrogen pipelines (repurposed NG + new build)	Demonstration / Scale-up	REPowerEU calls to upscale transmission, primarily via repurposing NG pipelines	Standardisation of verification/validation methods for overall safety is crucial	Key to connect supply & demand and accelerate uptake
Storage (mobile & stationary)	High-pressure compressed H ₂ tanks (350-700 bar)	Established commercial	Typical pressures 350-700 bar; some even higher	Need standardised tests referenced in text: fast filling, gas cycle, permeation	Part of broader safety/performance validation effort
Final use	Fuel cells (various electrolytes/temperatures)	Demonstration → Early commercial	Powering vehicles, stationary power, portable devices; high efficiency, fast refuelling	Durability / lifetime under real duty cycles	ORC discussed as an enabler to generate electricity for electrolysis (indirectly supports H ₂ pathways)
Cross-cutting → Enabler for Production	Organic Rankine Cycle (ORC) powering electrolysis	Early commercial	Uses solar, geothermal, or waste heat to run the ORC → generates electricity to power an electrolyzer (splits water into H ₂ /O ₂). Uses organic fluid with lower boiling point to convert heat to power efficiently.	heat-grade/scale match; integration economics; dynamic control/interface; low-GWP fluids & F-gas compliance; site/O&M practicality	Indirect enabler that improves energy efficiency of green H ₂ production by supplying electricity to electrolyzers from heat sources/waste heat.

Table 13 - Technology maturity map



11.2. Annex 2: demand scenario

The most recent and best-accepted hydrogen demand scenarios for 2030, 2040 and 2050 by sector (industry, transport, buildings and electricity) in Europe according to different studies⁴.

Year	Demand forecast	Industry	Transport	Building	Power	TOTAL DEMAND (in TWh/year)
2030	Guidehouse - EHB (2021) ⁵	294	21	12	12	339
2030	Deloitte/CHJU - Conservative (2023) ⁶	266	13	0	0	279
2030	Deloitte/CHJU - Moderate (2023)	303	30	0	0	333
2030	Deloitte/CHJU - Ambitious (2023)	353	35	0	0	388
2030	CHJU Roadmap - BAU (2019)	427	9	30	15	481
2030	CHJU Roadmap - Ambitious (2019) ⁷	497	70	33	65	665
2030	Aurora ⁸ - Low (2021)	400,32	4	12,51	0	416,83
2030	Aurora - Central (2021)	451	18	23	0	492
2030	Aurora - High (2021)	484,72	58,4	40,88	0	584
2030	ENTSOG ⁹ - Distributed (2022)	200	33	57	0	290
2030	ENTSOG - Global Ambition (2022)	224	53	45	0	322

⁴ Some scenarios leave sectors blank (zero entries) by design.

Power figures portray final H₂ use within the power sector (e.g., Speakers, P2G2P), not electricity consumption to produce H₂—avoid double counting.

Differences between earlier roadmaps (EC 2018) and 2021-2023 studies mirror updates in costs, infrastructure constraints and policies.

⁵ Please notice “Analysing future demand, supply, and transport of hydrogen” in Guidehouse - European Hydrogen Backbone” considers in industry category the followings: Iron & steel; Ammonia for fertilizers; High Value Chemicals (HVCs); Refining & fuel production; Industrial process heat (low, medium and high temperature); while in transport category it considers Road transport (only heavy-duty road freight), aviation and shipping.

⁶ Please notice the “Road transport (only heavy-duty road freight), aviation and shipping.” In Deloitte - Clean Hydrogen Partnership considers in industry category Iron & steel; Ammonia for fertilizers; Methanol; High Value Chemicals (HVCs); Refining; Industrial process heat (low, medium and high temperature); while in transport category Road transport (only heavy-duty road freight), international shipping, domestic shipping and port activities (cargo handling and port vessels). Power sector was not included in this analysis.

⁷ Please notice in “Hydrogen roadmap Europe: A sustainable pathway for the European energy transition” from FCH JU In industry category it considers Iron & steel; Ammonia for fertilizers; Methanol; High Value Chemicals (HVCs); Refining; Industrial process heat (low, medium and high temperature); while in transport category it considers Road transport, shipping and aviation.

⁸ Aurora Energy Research investigates in Iron & steel; Ammonia for fertilizers; Methanol; High Value Chemicals (HVCs); Refining; and Cement, as far as it concerns industry category; while transport category is considered in Road transport (mainly heavy-duty road freight), shipping and aviation.

⁹ ENTSO-G & ENTSO-E investigates on energy use (ex: Iron & steel) and nonenergy use (ex: Ammonia for fertilizers; Methanol; High Value Chemicals (HVCs); Refining), as far as it concerns industry category; while transport category is considered in Road transport (heavy-duty trucks, passenger cars, light trucks, buses, rail), shipping and aviation.



2030	BP - Net-zero (2020) ¹⁰	315,1263404	17,010168 91	16,5418 5991	0	348,6783693
2030	CAN - 1.5° C (2020)	445,3056644	321,87522 52	0	0	767,1808896
2030	DNV - Net-zero (2021)	292,1356961	1,7608757 88	9,61230 131	0	303,5088732
2030	EUCalc - Tech (2020)	262,9696335	49,782358 21	0	0	312,7519918
2030	IFS - 1.5 scenario (2019)	279,4796733	154,23666 14	18,0557 0456	15,829 13814	467,6011774
2030	JRC TIMES - Net-zero (2021)	283,8217357	207,68693 71	0,83408 4085	0	492,3427569
2030	JRC - GECO (2021)	269,63489	0,0678835 03	34,5405 0724	0	304,2432808
2030	McKinsey - Cost Optimal (2020)	262,9696335	15,013513 51	0	0	277,9831471
2030	McKinsey - Breakthrough (2020)	271,3104744	15,013513 51	15,0135 1351	0	301,3375014
2030	EC - Fit-for-55 (2022) ¹¹	129,987	93,324	0	0	223,311
2030	EC - REPowerEU (2022) ¹²	386,628	169,983	76,659	36,663	669,933
2040	Guidehouse - EHB (2021)	857	141	53	301	1352
2040	Deloitte/CHJU - Conservative (2023)	284	106	0	0	390
2040	Deloitte/CHJU - Moderate (2023)	397	210	59	0	666
2040	Deloitte/CHJU - Ambitious (2023)	552	278	145	0	975
2040	ENTSOG - Distributed (2022)	563	300	166	210	1239
2040	ENTSOG - Global Ambition (2022)	514	387	363	226	1490
2040	BP - Net-zero (2020)	373,8816367	412,95317 88	153,963 577	0	940,7983925
2040	CAN - 1.5° C (2020)	645,1796779	582,70836 12	0	0	1227,888039
2040	DNV - Net-zero (2021)	513,5652626	140,18369 59	102,631 3999	0	756,3803584
2040	EUCalc - Tech (2020)	263,8871707	123,80796 13	0	0	387,695132
2040	IFS - 1.5 scenario (2019)	413,0479837	216,75733 37	151,086 665	162,13 3442	943,0254243
2040	JRC TIMES - Net-zero (2021)	587,9843986	586,36111 16	0,27802 8028	0	1174,623538
2040	JRC - GECO (2021)	310,6455975	188,84889 66	27,2103 075	0	526,7048016

¹⁰ The reasearch Energy Outlook 2020 edition - Net-zero scenario from BP considers industry category as Existing industry feedstock use (ammonia, refineries and methanol and new energy use (ex: Steel)

¹¹ "Fit-for-55" from European Commission in the industry category includes Iron & steel; Ammonia for fertilizers; Refining; Industrial heat; while the transport category considers Road transport (Transport); Aviation (synthetic fuels); Maritime (bunker fuels)

¹² REPowerEU from European Commission investigates on Iron & steel; Ammonia for fertilizers; Refining; Industrial heat, as far as it concerns the industry category; the transport category considers while Road transport (Transport); Aviation (synthetic fuels); Maritime (bunker fuels).



2040	EC - Fit-for-55 (2022)	547,8526823	351,2052093	84,4078189	26,78422137	1010,249932
2050	Guidehouse - EHB (2021)	1200	285	155	626	2266
2050	Deloitte/CHJU - Conservative (2023)	341	202	0	0	543
2050	Deloitte/CHJU - Moderate (2023)	494	388	212	0	1094
2050	Deloitte/CHJU - Ambitious (2023)	725	526	494	0	1745
2050	CHJU Roadmap - BAU (2019)	445	85	207	43	780
2050	CHJU Roadmap - Ambitious (2019)	885	675	579	112	2251
2050	Aurora - Low (2021)	423,72	70,62	147,66	0	642
2050	Aurora - Central (2021)	545,4	242,4	222,2	0	1010
2050	Aurora - High (2021)	745,55	745,55	523,9	0	2015
2050	ENTSOG - Distributed (2022)	759	547	199	240	1745
2050	ENTSOG - Global Ambition (2022)	776	715	462	477	2430
2050	EC - Baseline (2018)	0	198	0	0	198
2050	EC - Energy Efficiency (2018)	0	264	0	231	495
2050	EC - Circularity (2018)	0	297	0	198	495
2050	EC - Electrification (2018)	0	330	0	198	528
2050	EC - Hydrogen (2018)	1584	1584	1221	429	4818
2050	EC - PtoX (2018)	165	297	0	396	858
2050	EC - COMBO (2018)	495	660	231	264	1650
2050	EC - 1.5TECH (2018)	957	1056	231	297	2541
2050	EC - 1.5LIFE (2018)	858	924	231	264	2277
2050	EC - MIX (2020)	528	1155	429	66	2178
2050	JRC - LCEO Net Zero (2020)	528	1782	0	792	3102
2050	BP - Net-zero (2020)	528,8353197	559,1668124	309,9510347	0	1397,953167
2050	CAN - 1.5°C (2020)	630,1339174	621,8630057	0	0	1251,996923
2050	DNV - Net-zero (2021)	749,5556496	433,2594796	191,436421	0	1374,25155
2050	EUCalc - Tech (2020)	265,0236949	168,4139446	0	0	433,4376395
2050	IFS - 1.5 scenario (2019)	450,6802824	203,8953355	181,0787148	253,0965958	1088,750928
2050	JRC TIMES - Net-zero (2021)	674,4511154	856,048299	0	0	1530,499414
2050	JRC - GECO (2021)	295,5366829	332,8719139	10,25247723	0	638,6610741
2050	McKinsey - Cost Optimal (2020)	328,0281921	595,536036	225,2027027	121,1154676	1269,882398
2050	McKinsey - Breakthrough (2020)	708,3705344	595,536036	580,5225225	155,1396396	2039,568733
2050	EC - Fit-for-55 (2021)	919,1774848	549,7131606	350,5340141	73,23214461	1892,656804

Table 14 - The most recent and best-accepted hydrogen demand scenarios for 2030, 2040 and 2050 by sector



11.3. Annex 3: Average demand per category in 2030

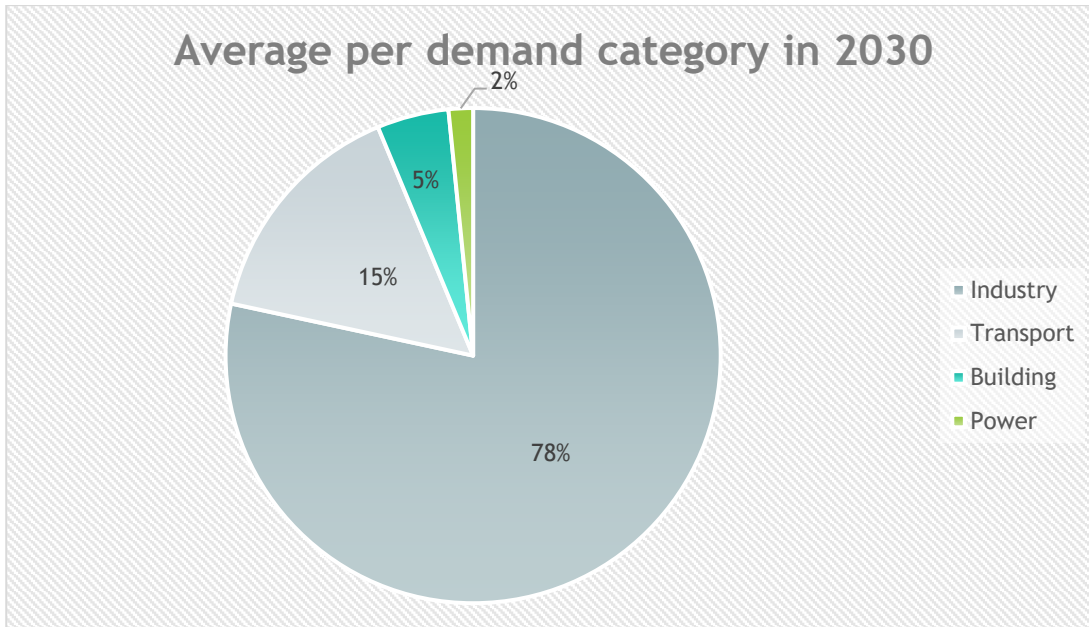


Figure 7- Average per demand category according to the collected studies in 2030

11.4. Annex 4: Average demand per category in 2040

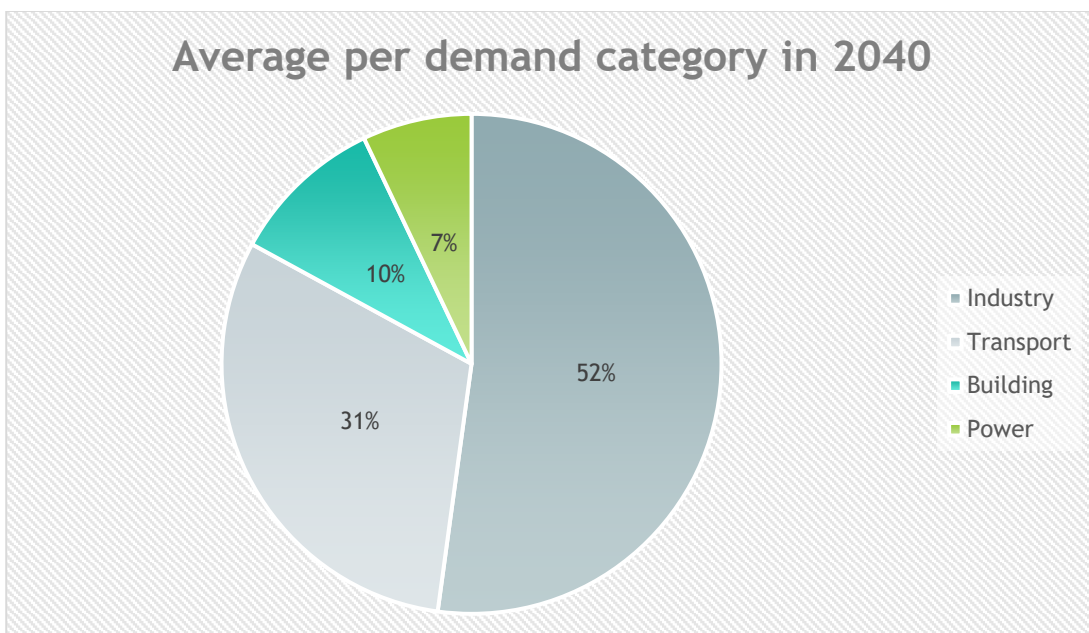


Figure 8 - Average per demand category according to the collected studies in 2040



11.5. Annex 5: Average demand per category in 2050

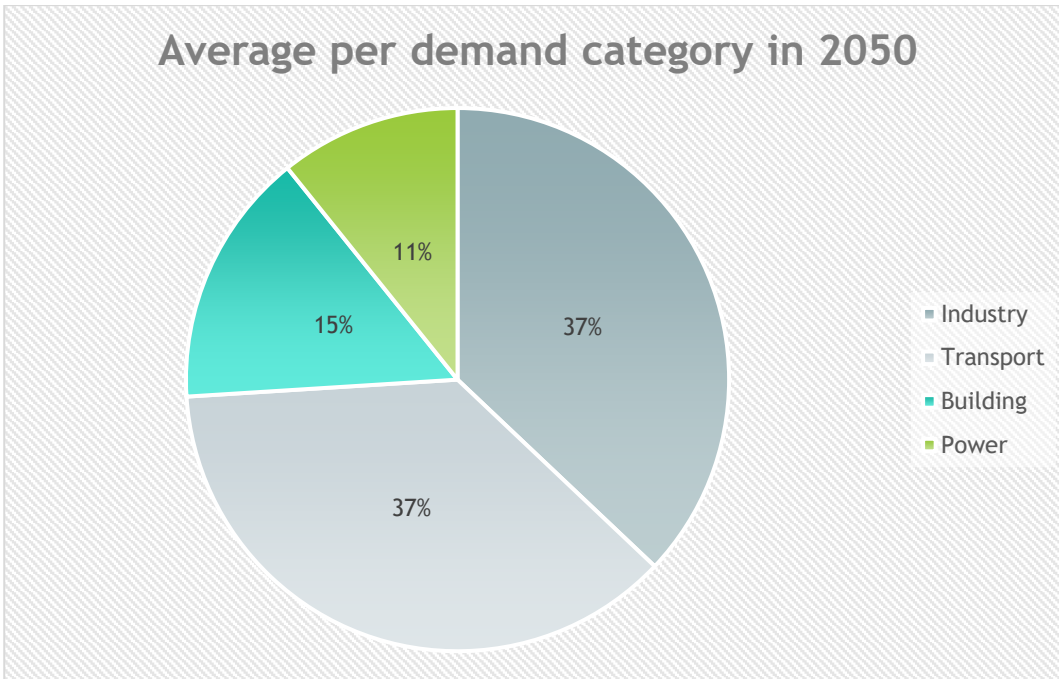


Figure 9 - Average per demand category according to the collected studies in 2050

11.6. Annex 6: Average demand per category through the years

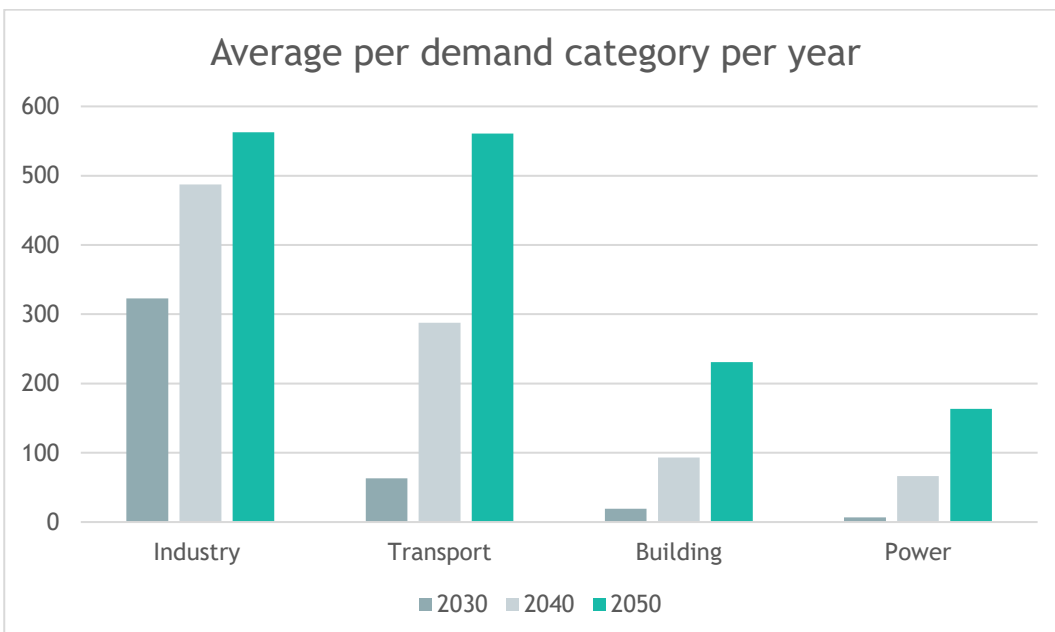


Figure 10 - Average per demand category according to the collected studies per each year

11.7. Annex 7: elaboration of regulations of economic framework assessment report and policy framework assessment report

Country	Regulation
Germany	<ul style="list-style-type: none"> - German Energy Act (EnWG) - Federal Immission Control Act (BImSchG)



	- Renewable Energy Sources Act (EEG 2023)
Italy	Legislative Decree No. 152/2006, known as the Environmental Code
Austria	<ul style="list-style-type: none"> - Hydrogen Promotion Act (Wasserstoffförderungsgesetz, WFöG) - Renewable Gas Act (Erneuerbare-Gase-Gesetz, EGG) - Renewable Energy Expansion Act (Erneuerbaren-Ausbau-Gesetz, EAG) - Hydrogen Strategy for Austria - “Comprehensive Assessment of the Potential for Efficient Heating and Cooling” (Umfassende Bewertung des Potenzials für eine effiziente Wärme- und Kälteversorgung) - Electricity Act 2010 (Elektrizitätswirtschafts- und -organisationsgesetz 2010, ELWOG 2010)
Poland	<ul style="list-style-type: none"> - Poland’s Act of 21 Nov 2024 - Energy Policy of Poland until 2040 (EPP2040). - Poland’s National Energy and Climate Plan for the years 2021-2030 (NECP) - Strategy for Responsible Development for the period up to 2020 (including the perspective up to 2030).
Czech Republic	<ol style="list-style-type: none"> 1. Energy Act (No. 458/2000 Coll.) 2. Act on Fuels (No. 311/2006 Coll.) 3. Air Protection Act (No. 201/2012 Coll.) 4. Act on Supported Energy Sources (No. 165/2012 Coll.) 5. Decree No. 18/1979 Coll.
Slovenia	<ol style="list-style-type: none"> 6. ZIAG; 7. ReNPRP30; 8. Strategy for the development of transport in the Republic of Slovenia until 2030; 9. Slovenia Action programme for alternative fuels for transport 2022 and 2023; 10. NEPN - Comprehensive National Energy and Climate Plan 11. Energy law - EZ2: Article 115 of the Energy Act (EZ-1) 12. Electricity supply act; 13. Energy efficiency act; 14. Gas supply act; 15. Act on the promotion of the use of renewable energy sources;
Hungary	Hungary’s National Hydrogen Strategy (NHS)
Croatia	<ol style="list-style-type: none"> 16. Law on Biofuels for Transport (OG, No. /09, 145/10, 26/11, 144/12, 14/14, 94/18 and 52/21) 17. Law on Electricity (OG. No. 11/21, 83/23); 18. Law on Renewable Energy Sources and High-Efficiency Cogeneration (OG No. 138/21 and 83/23)

Table 15 - Elaboration of regulations of D.2.2.1 - Economic Framework assessment report and D2.1.1 - Policy Framework Assessment Report

11.8. Annex 8: data regarding Hydrogen strategies going on around Europe

COUNTRY	Type of financial strategy	Description
Germany	FINANCIAL INCENTIVES FOR HYDROGEN	<ul style="list-style-type: none"> - National Hydrogen Strategy (NWS): Launched in June 2020 with €9 billion for hydrogen, of which €7 billion for the domestic hydrogen economy and €2 billion for international partnerships (production, infrastructure, R&D). - IPCEI Projects: Germany supports 62 IPCEI hydrogen projects with over €8 billion in public funds, aiming to mobilise around €33 billion in private investment. - KfW Programs: KfW provides loans and grants to boost hydrogen innovation and industrial applications, helping scale technologies across multiple sectors. - Carbon Contracts for Difference (CCfD): CCfDs bridge the cost gap between low-carbon hydrogen and fossil fuels; in



		<p>October 2024, Germany awarded the first CCfDs, granting up to €2.8 billion to 15 companies to decarbonise their production processes.</p>
	REGIONAL/NATIONAL FUNDING SCHEMES	<ul style="list-style-type: none"> - H2Global Initiative: Germany has established the H2Global Foundation to facilitate long-term contracts, bridging the gap between supply and demand for green hydrogen. This initiative aims to create a reliable market for green hydrogen by securing purchase agreements. - State-Level Programs: various federal states, such as Bavaria and North Rhine-Westphalia, provide additional funding for hydrogen pilot projects, reflecting regional commitments to advancing hydrogen technologies. - IPCEI-projects with German partners - NIP II National Innovation Program Hydrogen and Fuel Cell Technologies - Energy Research Program - HyLand-Program - KfW-Programs <p>and further 50 programs, with hydrogen being involved Additional programs of the German States</p>
		<p>In synthesis, together, these instruments aim to make low-carbon hydrogen available at scale and at falling cost—anchoring value creation in Germany while securing imports—to decarbonise hard-to-abate sectors and strengthen energy security.</p> <p>The peculiar aspect of adopted strategies is the focus on scale & market making through the largest public funding mix; CCfDs to bridge green premium; H2Global to secure imports via long-term contracts; KfW financing (incl. core network).</p>
Italy	FINANCIAL INCENTIVES FOR HYDROGEN	<p>Italy actively participates in the Important Projects of Common European Interest (IPCEI) on hydrogen. In particular, the IPCEI Hydrogen 1 (Hy2Tech) supports research and development activities across the hydrogen value chain, with funding provided to six companies and two research institutions in Italy. Additionally, the Ministry of the Environment and Energy Security (MASE) has launched a public consultation to define tariff incentives for renewable hydrogen production, aiming to stimulate investments in industrial and transport sectors. Italy has recently developed the national hydrogen strategy 2024.</p>
	REGIONAL/NATIONAL FUNDING SCHEMES	<p>Italy’s energy and climate policies aim at carbon neutrality by 2050, combining national strategies (National Hydrogen Strategy, PNIEC) with regional actions. The country uses a broad mix of financial and regulatory tools to support both hydrogen development and waste heat recovery, boosting decarbonisation, energy efficiency and innovation.</p> <ul style="list-style-type: none"> • Hydrogen: About €3.64 bn from PNRR goes to hydrogen (industrial use, refuelling, hydrogen valleys), complemented by grants/loans for production, support for H₂ infrastructure (stations, pipelines) and tax incentives such as “Industry 4.0” credits.



		<ul style="list-style-type: none"> • Hydrogen Valleys: Regional pilot projects create local ecosystems for production-storage-use, co-financed by national and regional funds. • Waste heat recovery: Roughly €1 bn PNRR supports efficiency projects, including industrial and district heating heat recovery. • Market & tax tools: White certificates (TEE) reward energy savings, while Ecobonus/Superbonus and other tax deductions support investments in heat recovery equipment and efficiency upgrades. • Regional & non-financial support: Regions add their own funding lines, and Italy simplifies procedures and permitting to speed up deployment of both hydrogen and waste heat projects.
	<p>Main goals:</p> <ul style="list-style-type: none"> - Decarbonization: hydrogen will be used in hard-to-abate sectors, contributing to emissions reductions in industries such as steel, cement, heavy transport, shipping and aviation. - Energy integration: fostering the creation of an integrated, resilient and flexible energy system, with hydrogen serving as both an energy carrier and storage tool. - Industrial development: strengthen the national hydrogen supply chain to foster technological innovation and employment, consolidating Italy's role in the European context. - Energy security: diversify energy supply sources, reducing dependence on fossil fuels. - Geopolitical role: positioning Italy as a strategic hub in the Mediterranean for the import-export of hydrogen and its derivatives. <p>In Italy PNRR-driven funds are specifically deployed, where €3.64 bn for industry, HRS and hydrogen valleys; tariff incentives for renewable H₂.</p>	
Austria	FINANCIAL INCENTIVES FOR HYDROGEN	Austria has outlined a National Hydrogen Strategy 2022 that includes financial incentives for hydrogen production and utilization projects, particularly in the industrial and transport sectors.
	REGIONAL/NATIONAL FUNDING SCHEMES	Austria offers national funding programs for hydrogen-related projects, supporting initiatives ranging from research and development to the construction of hydrogen infrastructure. Incentives and subsidies within the EAG (Renewable Energy Expansion Act). Anchored in the EAG is an exemption from the renewables subsidy flat rate and subsidy contribution for electrolysis plants for the production of renewable hydrogen, exemption from grid utilisation and grid provision fees for electricity for electrolysis plants for the production of renewable hydrogen. Additionally, within EAG CAPEX support for electrolysers is planned for around 40 M€ per year.
	<p>Key aspects are:</p> <ul style="list-style-type: none"> • Replace fossil-based hydrogen with climate neutral hydrogen in energy intensive industries: 80% until 2030. • Install 1GW of electrolyser capacity by 2030. • Create a supporting framework for the production of renewable hydrogen. • Establish the production of hydrogen as integral part of the energy system. • Develop a targeted hydrogen infrastructure. • Enhance international partnerships for climate neutral hydrogen. • Strengthen the innovation and technology potential in Austria through focused development of hydrogen technologies. 	



		<p>In Austria fee/tariff exemptions for electrolysis electricity have been adopted in order to reach 1 GW electrolyzers by 2030 and replace 80% of fossil H₂ in EIs by 2030.</p>
Poland	<p>FINANCIAL INCENTIVES FOR HYDROGEN</p>	<p>Poland supports hydrogen mainly through its National Hydrogen Strategy 2030 and several targeted funding instruments. The National Fund for Environmental Protection and Water Management (NFOŚiGW) finances hydrogen projects, including hydrogen buses under the “Green Public Transport” programme and infrastructure via the “Support for electric vehicle charging and hydrogen refuelling infrastructure” scheme (PLN 870 million).</p> <p>Under the National Recovery and Resilience Plan, Bank Gospodarstwa Krajowego manages €640 million in non-repayable support for hydrogen production, storage and transport projects, reserved for installations of 20 MW or more. In parallel, the Modernisation Fund, also managed by NFOŚiGW, will provide PLN 5 billion in grants for hydrogen investments, with eligibility starting from 1 MW plant capacity; the programme details have just been consulted publicly (January 2025). Overall, these instruments aim to cut emissions, scale hydrogen technologies and stimulate innovation in Poland’s energy sector.</p>
	<p>REGIONAL/NATIONAL FUNDING SCHEMES</p>	<p>Poland supports hydrogen R&D and deployment through several research and investment programmes, but a large chunk of planned money is currently blocked at EU level.</p> <p>The National Centre for Research and Development runs the strategic programme “New Technologies for Energy”, which includes PLN 141.2 million specifically for hydrogen production and use, and the broader “New Energy” programme, offering preferential loans (up to 85% of eligible costs, partly convertible into a grant) across four areas: smart energy cities, multi-fuel units with heat/cold storage, stable zero-emission sources, and self-sufficient energy clusters (each with budgets of PLN 150-250 million).</p> <p>According to the Polish Hydrogen Strategy, EUR 800 million (~PLN 3.8 billion) from the National Recovery Plan was supposed to finance green and low-emission hydrogen capacity and its use in energy, industry and low/zero-emission transport (also via NFOŚiGW programmes and IPCEI projects). However, these funds have not yet reached Poland due to lack of agreement with the European Commission on required “milestones”, casting doubt on achieving some 2030 hydrogen targets. In parallel, the Modernisation Fund (EU ETS-financed) could channel up to PLN 60 billion to Poland by 2030 for energy efficiency and zero-emission transport, representing a major potential source for hydrogen-related investments.</p>
	<p>Poland’s hydrogen policy is driven by the Polish Hydrogen Strategy (PHS), which sets six core goals: deploy hydrogen in power and heating, use it as an alternative fuel in transport, support industrial decarbonisation, build new low/zero-carbon hydrogen production, ensure safe transmission/storage, and create a stable regulatory framework. The Strategy promotes a broad technology mix (electrolysis, biomass and waste gasification/pyrolysis, biogas/biomethane reforming, and fossil routes with CCS/CCU) and explicitly pushes</p>	



	<p>regional hydrogen valleys to build full local value chains (production-transport-storage-use) and exploit Polish R&D and manufacturing potential.</p> <p>By 2030, key targets include 50 MW of low-carbon hydrogen capacity by 2025 and 2 GW by 2030, at least five hydrogen valleys, 100-250 H₂ buses by 2025 and 800-1000 by 2030, and at least 32 hydrogen stations by 2025, alongside sectoral agreements and innovation ecosystems (Hydrogen Valleys Innovation Ecosystem, Hydrogen Technology Centre). Overall, Poland's main objective is to build a diversified technology portfolio and regional hydrogen ecosystems that accelerate decarbonisation in energy-intensive sectors and support a gradual move toward a zero-emission economy.</p>	
<p>Czech Republic</p>	<p>FINANCIAL INCENTIVES FOR HYDROGEN</p>	<p>The Czech Republic's hydrogen strategy is structured in three phases. By 2030, the "Local Islands" phase aims to deploy at least 400 MWe of decentralised electrolysers producing around 20,000 tons of RFNBO hydrogen per year. In parallel, the "Global Bridges" phase plans cross-border hydrogen pipelines from Germany and Ukraine/Slovakia to import cheaper hydrogen, while the later "New Technologies" phase (2040-2060) foresees using advanced options such as geothermal energy and new-generation nuclear for low-cost hydrogen production. Because technological and political developments are uncertain, concrete targets are mainly set only up to 2030.</p>
	<p>REGIONAL/NATIONAL FUNDING SCHEMES</p>	<p>The updated Czech Hydrogen Strategy mainly aligns the country with the new EU climate and energy framework and maps the subsidy tools that can bankroll hydrogen projects. It responds to key EU policies and regulations (Paris Agreement, EU Hydrogen Strategy, Fit for 55, RED and its Delegated Acts on RFNBOs, AFIR, CEEAG, GBER, REPowerEU, etc.), so that Czech rules on hydrogen production, infrastructure and support schemes remain compatible with EU law and funding.</p> <p>At national level, several funding programmes support hydrogen and related technologies:</p> <p>Modernisation Fund - main energy transition tool, financed by ETS revenues, with sub-programmes for:</p> <ul style="list-style-type: none"> RES+ (PV plus storage, including electrolysers and H₂ storage), ENERG ETS (industrial emission reduction, including switching to renewable H₂), TRANSCoM (zero-emission vehicles for companies, incl. H₂), TRANSGov (zero-emission fleets for public entities), GREENGAS (renewable gas production/storage, repurposing gas networks, hydrogen valleys), I+ (complex innovation projects assessed with the EIB). <p>Innovation Fund - supports innovative low-carbon technologies in energy and industry.</p> <p>Operational Programme Just Transformation - funds projects in three coal regions, with energy transition as a key axis (including hydrogen where relevant).</p> <p>Recovery and Resilience Facility - backs clean mobility and reduced fossil-fuel dependence, especially decarbonising road transport.</p> <p>Operational Programme Transport - finances hydrogen refuelling stations and, in future, linear H₂ infrastructure.</p> <p>Integrated Regional Development Programmes - support multimodal urban mobility through purchase of zero-emission vehicles and creation of refuelling stations for public transport.</p>



	<p>The updated Czech hydrogen strategy sets very concrete 2030-oriented goals: build at least 400 MWe of electrolysers, create hydrogen valleys (especially in former coal regions), and repurpose parts of the gas grid to carry hydrogen and blends. By 2024-2026 it wants to simplify permitting, fine-tune subsidy schemes, set up support calls for valleys, and complete a full regulatory framework (guarantees of origin, standards, certificates). In parallel, it prepares hydrogen mobility (vehicles + stations), explores storage options, promotes exports of Czech hydrogen technologies, and supports awareness, education and applied research—all organised within the three-phase structure of the Czech hydrogen strategy.</p>	
Slovenia	FINANCIAL INCENTIVES FOR HYDROGEN	<p>There is no specific legal framework established in Slovenia, that would regulate the areas of green hydrogen infrastructure development/hydrogen policy in general. Such acts have not yet been adopted in the Republic of Slovenia.</p> <p>While there is no dedicated national hydrogen strategy, Slovenia has included hydrogen-related goals in its National Energy and Climate Plan, providing incentives for industrial decarbonization and the development of large-scale electrolysers.</p> <p>Slovenia has taken a significant step forward in the development of clean hydrogen technologies by signing a cooperation memorandum with the EU Clean Hydrogen Partnership. This collaboration aligns with the nation's renewable energy targets and reinforces its commitment to advancing the North Adriatic Hydrogen Valley project.</p>
	REGIONAL/NATIONAL FUNDING SCHEMES	<p>Ministry of the Environment, Climate, and Energy - Call for proposals for the co-financing of the purchase of vehicles for the establishment of an emission-free public passenger transport line. Subsidies for the purchase of EVs - natural persons and private sector.</p> <p>Subsidy up to 7200,00 € for the purchases of new or used (up to 4 years) EVs (including FCEVs). The purpose of the public call is to support individuals in the transition to zero-emission mobility by granting financial incentives for the purchase of CO₂-free electric vehicles intended for road transport.</p> <p>ECO-FUND 118FS-PO24 Non-returnable financial incentives for new investments in energy efficiency and renewable energy sources for businesses</p>
	<p>Main goals are cut emissions in industry and mobility, and build capacity, despite the absence of a dedicated national Hydrogen Strategy.</p> <p>In Slovenia there's still no strategy, nevertheless emissions aim to be cut and capability built using existing instruments while the national framework matures.</p>	
Hungary	FINANCIAL INCENTIVES FOR HYDROGEN	<p>Hungary is promoting hydrogen mainly through financial incentives for green hydrogen production and its use in transport, backed by several national and EU-linked programmes (RRF, OP Plus, REPowerEU, green manufacturing and technology schemes). Key tools include support for converting surplus renewable electricity into hydrogen/biomethane, the Green Bus and Green Truck Programmes (vehicles, production and refuelling), and dedicated calls under environmental, energy-efficiency and innovation programmes. All these measures are framed by Hungary's 2021 National Hydrogen Strategy, which aims to introduce clean hydrogen to the domestic market and build the necessary infrastructure and industrial base.</p>



	REGIONAL/NATIONAL FUNDING SCHEMES	Hungary offers funding for hydrogen-related initiatives, particularly for the development of green hydrogen production and its use in mobility and industry. Hungary does not yet have a dedicated, comprehensive legal framework for hydrogen. Instead, hydrogen projects fall under existing energy, industrial, and environmental laws, which were not originally designed for hydrogen applications. In Hungary, one of the most important pieces of legislation for hydrogen is Act XL of 2008 on Natural Gas Supply, which applies to the licensing of facilities for the production, use and storage of hydrogen, as well as pipelines for the transportation of hydrogen. In addition, the Hungarian government has adopted several strategic documents and plans. The main objective of these plans is to have strategic level documents and strategic plans to promote the hydrogen economy.
	Main objectives are: <ul style="list-style-type: none"> • Production of large volumes low-carbon and decentralized carbon-free hydrogen; • Decarbonisation of industrial consumption, partly with hydrogen; • Green transport; • Electricity and (natural) gas support infrastructure <p>In Hungary, despite legal framework still evolving production and mobility are put first.</p>	
Croatia	FINANCIAL INCENTIVES FOR HYDROGEN	Croatia’s National Hydrogen Strategy sets four strategic goals and related performance indicators for the uptake of clean hydrogen, aligning national planning with EU climate and energy ambitions. The strategy is anchored in a broad set of national documents covering energy, climate, transport and alternative fuels—such as the Croatian Hydrogen Strategy 2050, the National Energy and Climate Plan, the National Recovery and Resilience Plan, the Low-Carbon Development Strategy and the Energy Development Strategy. These are complemented by laws regulating biofuels, alternative fuel infrastructure, and renewable energy/cogeneration. Together, this framework defines Croatia’s long-term pathway for developing hydrogen production, infrastructure and end-use across energy, industry and mobility.
	REGIONAL/NATIONAL FUNDING SCHEMES	To meet the objectives stated in the National Recovery and Resilience Plan 2021-2026 (NRRP) and National Programme for Cohesion and Coherence (NPCC) envelope from 2021 to 2027, the Ministry of Economy decided to subsidize the construction of filling stations (CAPEX subsidy) for hydrogen vehicles with a non-reimbursable EUR 23 million (EUR 15 million in 2024 and EUR 8 million in 2026). The highest amount of support per HRS station is EUR 2 million for passenger cars, and EUR 3.5 million for buses and heavy vehicles. Beneficiaries of grants in accordance with this Program can be micro, small, medium, and large enterprises
		Croatia’s hydrogen strategy sets clear long-term targets for production, uptake and innovation out to 2050. It plans to scale electrolyser capacity from 70 MW by 2030 to 2,750 MW by 2050, raising hydrogen’s share of total energy use from 0.2% to 11% over the same period. Hydrogen use is to expand across industry, transport and energy, with 15 refuelling stations by 2030 and 100 by 2050, while research and innovation are supported through targets of 5 hydrogen-related patents by 2030 and 50 by 2050. Overall, Croatia focuses on concrete capacity and market milestones, combined with a strong push for hydrogen R&D.

Table 16 - Elaboration of D2.2.2 data regarding Hydrogen strategies going on around Europe

11.9. Annex 9: examples of projects funded through PPPs

Examples of projects funded	DESCRIPTION	OUTCOME
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through PPPs EXAMPLE		
HYDROGEN BUS PROJECT (UK AND GERMANY)	Deployment of hydrogen-powered bus fleets in various cities through mixed public and private funding	Reduction in urban pollution and increased adoption of hydrogen in public transportation.
H2PORTS PROJECT (SPAIN)	Implementation of hydrogen technology for the decarbonization of port operations in the Port of Valencia.	Reduction of CO ₂ emissions in port logistics activities and increased interest in hydrogen adoption for maritime hubs.
HYDEAL AMBITION PROJECT (FRANCE AND SPAIN)	A large-scale initiative for the production and distribution of green hydrogen, involving both private companies and public entities.	Lower production costs for green hydrogen and the development of a European ecosystem for its use.
BRENNER MOTORWAY (ITALY)	An infrastructure project financed through PPPs for the management and maintenance of the motorway, with investments in low-emission solutions, including hydrogen mobility.	Improved transport efficiency and reduced environmental impact.
HAMBURG GREEN HYDROGEN HUB	In Hamburg, a significant PPP has been established to develop the Hamburg Green Hydrogen Hub. The project is a collaboration between public authorities and private companies, including Shell, Mitsubishi Heavy Industries, Vattenfall, and Wärme Hamburg. The partnership facilitates the sharing of resources, expertise, and risks, contributing to the project's success.	Decarbonize the port's economy by producing green hydrogen through a 100 MW electrolyzer, utilizing renewable energy sources Enhanced Financial Viability: Access to diverse funding sources reduces the financial burden on individual entities. Accelerated Implementation: Combined efforts expedite project development and deployment. Policy Alignment: Ensures that projects align with governmental policies and regulatory frameworks.
GET H2 Nukleus (Lower Saxony & NRW, Germany)	Industry-led project to build the first publicly accessible, regulated hydrogen network in Germany, linking green H ₂ production in Lingen with industrial users in the Ruhr area.	Achieved IPCEI backing and regulatory recognition as part of the future German hydrogen core network; demonstrates conversion and expansion of existing gas infrastructure for open-access hydrogen transport.
Clean Hydrogen Coastline (Frankfurt-Rhine-Main Region)	Large-scale hydrogen programme led by utilities and network operators to create a regional hydrogen backbone in the Frankfurt-Rhine-Main area, connecting local production, the national hydrogen core network and key industrial and mobility users. It follows the same logic as the northern German "Clean Hydrogen Coastline" IPCEI: coordinated investments along the value chain (production, pipelines, storage, industrial and transport offtake) under a public-private partnership framework.	Lays the groundwork for a dedicated regional H ₂ network and integrated hydrogen economy in the Frankfurt-Rhine-Main region; secures cooperation between multiple energy suppliers and TSOs, links the region to the German hydrogen core grid and prepares large industrial and mobility users to switch to low-carbon hydrogen.
H2 Valle Padana Project	Interregional hydrogen corridor in Northern Italy based on public-private participation (e.g. SNAM, SAPIO, FNM, motorway operators, local authorities) to deploy hydrogen refuelling infrastructure along key TEN-T routes (Brenner and Mediterranean corridors).	Lays the groundwork for an interoperable hydrogen corridor across multiple Italian regions, aligning TEN-T transport planning with national PNRR priorities; secures coordinated investment from major infrastructure operators and public authorities;



	Funded through PNRR Mission 2 - Component 2, complemented by regional funds and regulatory support for sustainable mobility, the project is designed as a systemic approach to decarbonising heavy road transport and connecting ports, interports and logistics areas.	provides a reference model for how PPPs can structure long-distance H ₂ refuelling networks for heavy-duty transport in Europe.
Hydrogen Valley in Puglia (Puglia Green Hydrogen Valley)	Large-scale regional hydrogen valley in Puglia led by Edison, Saipem and Sosteneo through the SPV “Puglia Green Hydrogen Valley S.r.l.”, with IPCEI Hy2Infra support. The project foresees two to three green hydrogen production plants around Brindisi and Taranto (and Cerignola in early concepts), with 160-220 MW of electrolysis powered by ~260-400 MW of solar PV. The hydrogen will supply Italy’s largest energy and steel hub in Taranto, other local industries, sustainable mobility and, partly, the gas grid, in synergy with Snam’s Apulia Hydrogen Backbone between Brindisi and Taranto.	Recognised by the European Commission as an IPCEI Hy2Infra project and awarded up to ~€370 million of public funding, positioning Puglia as a keystone in Europe’s green hydrogen infrastructure. The project creates a flagship industrial hydrogen valley for the decarbonisation of the Taranto steel cluster and associated industries, and anchors investment in dedicated H ₂ transport infrastructure in Southern Italy.
Hydrogen Valley di Bolzano - H2 Südtirol	Pioneering regional hydrogen valley centred on the Hydrogen Centre in Bolzano Sud, developed by IIT - Institut für Innovative Technologien with the Autonomous Province of South Tyrol and partners such as Autostrada del Brennero, SASA and Alperia. Starting from an ERDF-funded H ₂ centre with electrolyzers, storage and a public HRS, the valley has been expanded through EU projects (CHIC, HyFIVE, JIVE, MEHRLIN, LIFEalps, REVIVE) to a regional network of H ₂ buses, cars, refuelling stations and demonstration activities along the Brenner corridor.	Delivered a long-running, operational hydrogen ecosystem: over 120,000 kg of green H ₂ produced and refuelled, >1.2 million km driven by fuel-cell buses, high station availability and strong public acceptance. Recognised on the EU Hydrogen Valley Platform, it now underpins the wider South Tyrolean/Brenner Corridor hydrogen valley vision and provides a reference model for alpine, mobility-focused hydrogen regions.
Hydrogen Pilot Project di FNM e Trenord (H2iseO)	Public-private pilot project promoted by FNM, FERROVIENORD and Trenord to develop a hydrogen-based mobility system in Val Camonica along the non-electrified Brescia-Iseo-Edolo railway line. The project includes the purchase of Alstom hydrogen trains, construction of hydrogen production, storage and distribution plants (Brescia, Iseo, Edolo) and a new maintenance & refuelling facility in Rovato, financed through direct FNM investment, PNRR Mission 2 funds and support from Lombardy Region and energy partners.	Delivers Italy’s first hydrogen-powered railway line and kick-starts the H2iseO Hydrogen Valley, creating a concrete hydrogen supply chain for local public transport. The pilot establishes technical, regulatory and economic references for scaling hydrogen rail and bus services and for extending the hydrogen value chain to other sectors in the territory.
Hydrogen Hub di Civitavecchia	Hydrogen hub centred on the port of Civitavecchia, one of the three sites of the LIFE3H project (with Terni and Altopiano delle Rocche) and	Creates the first Italian **port hydrogen valley**, demonstrating an integrated RES-H ₂ ecosystem for port mobility and logistics. The combination of LIFE3H



	<p>complemented by the PNRR projects “H2 Civitavecchia” (3 MW electrolysis with 4.5 MW off-grid PV in a disused industrial area) and “HRS Civitavecchia”. The hub will produce, store and distribute green hydrogen for zero-emission buses and other port/retro-port vehicles, making Civitavecchia the first Italian port hydrogen valley, in cooperation with Regione Abruzzo (coordinator), AdSP Mar Tirreno Centro Settentrionale, Port Mobility, CFFT, Greenture/Snam4Mobility, Rampini and several universities.</p>	<p>and PNRR funding fully finances the initial production and refuelling assets, positions Civitavecchia as a green mobility hub on key European corridors, and provides a replicable model for other Italian ports seeking to valorise disused industrial areas with hydrogen projects.</p>
Orlen Hydrogen Hub Włocławek	<p>Automotive-grade hydrogen hub developed by ORLEN at the ANWIL chemical plant in Włocławek. The project builds a purification unit for by-product hydrogen from brine electrolysis, upgrading it to fuel-cell grade, with a modular capacity ultimately up to ~600 kg/h (~14 t/day). It includes logistics infrastructure for loading hydrogen into rail tank cars and road trailers, and is linked with public hydrogen refuelling stations as part of the EU-backed “Clean Cities - Hydrogen mobility in Poland” programme under the Connecting Europe Facility.</p>	<p>One of Poland’s first large automotive-grade hydrogen hubs, creating an anchor supply point for a national H₂ mobility network. It enables the rollout of multiple public HRS and hydrogen bus/truck projects co-funded by the EU, demonstrates industrial-to-mobility hydrogen valorisation, and provides a reference model for how corporate refineries can become hydrogen suppliers for zero-emission transport.</p>
Budapest Hydrogen Mobility Project	<p>Package of hydrogen mobility pilots in the Budapest area, coordinated by HUMDA Hungarian Mobility Development Agency under the National Hydrogen Strategy. It started with a 3-week pilot in 2022 on a route between Budapest and Vecsés using a Solaris hydrogen bus, then evolved into the 2023-24 “big hydrogen project” with Solaris and Caetano fuel-cell buses in regular service in the Budapest agglomeration and six major cities. In parallel, Hungary’s first public hydrogen filling station opened in Budapest (Illatos út), operated by Linde Gáz Magyarország and designed primarily to supply these pilots and other early adopters.</p>	<p>Delivered Hungary’s first hydrogen bus routes and first public hydrogen refuelling station, providing real-world operational data on buses, refuelling and logistics. It created a strategic cooperation framework between major state and private players (HUMDA, Volánbusz, MÁV, MOL, Waberer’s, Linde), positioned Budapest as the national hub for hydrogen mobility and laid the foundations for future large-scale H₂ bus and truck deployment.</p>
MOL Green Hydrogen Refinery (Danube Refinery, Százhalombatta)	<p>10 MW green hydrogen plant built inside MOL’s Danube Refinery in Százhalombatta, Hungary. The Plug Power PEM electrolysis unit uses renewable electricity to produce around 1,600 t/year of green hydrogen, replacing part of the refinery’s grey hydrogen and reducing CO₂ emissions by about 25,000 t/year (~5,400 cars). The €22 million project is fully financed</p>	<p>Puts into operation a flagship industrial decarbonisation project that directly cuts one sixth of MOL Group’s refinery-related CO₂ emissions pathway and opens the way for similar projects in Bratislava and Rijeka. It demonstrates that purely corporate investments, driven by EU regulation (RED III, Fuel Quality, RFNBO quotas) and climate strategy, can scale green hydrogen in</p>



from MOL's balance sheet and is the largest green hydrogen plant in Central and Eastern Europe.

refining without upfront public co-funding, creating an important reference for other EU refineries.

Table 17 - Examples of projects funded through PPPs

11.10. Annex 10: examples of community-driven projects

Examples of community-driven projects EXAMPLE	DESCRIPTION	OUTCOME
ORKNEY HYDROGEN PROJECT (SCOTLAND, UK)	A community-led initiative that produces hydrogen using excess wind and tidal energy to power ferries and heating systems. Tidal power devices located at the European Marine Energy Centre test site at the Fall of Warness, in the sea just west of the island of Eday, and the Eday Renewable Energy community-owned onshore wind turbine, route their surplus electricity to a 500kW electrolyser, which generates hydrogen by splitting water. The hydrogen is stored as compressed gas then transported on a trailer by road and sea to Kirkwall, the capital of Orkney. There it powers a fuel cell to generate clean electricity on demand.	A circular energy economy that reduces fossil fuel dependency and benefits the local population.
ENERGIEGENOSSENSCHAFTEN (GERMANY)	Over 900 energy cooperatives in Germany have successfully implemented local renewable energy projects, including hydrogen production and distribution.	Increased energy independence for local communities and widespread adoption of green energy.
HVIDOVRE GREEN HYDROGEN COMMUNITY PROJECT (DENMARK)	A municipality-driven initiative where local residents co-own and benefit from hydrogen production used for transport and heating.	Greater public engagement in green energy projects and enhanced local energy resilience.
EFARM PROJECT IN NORTH FRIESLAND	Initiated by GP JOULE, the project involves local citizens and businesses in the production of green hydrogen using wind energy. The hydrogen is utilized for transportation and heating within the community, promoting local sustainability and energy independence.	Demonstrating how community involvement can lead to successful implementation of renewable energy solutions. Economic empowerment: it generates local employment and retains economic benefits within the community. Environmental stewardship: it encourages sustainable practices tailored to local ecological contexts. Social cohesion: it strengthens community bonds through collective action and shared goals

Table 18 - Examples of community-driven projects



11.11. Annex 11: examples of hybrid funding projects

Examples of hybrid funding projects EXAMPLE	DESCRIPTION	OUTCOME
NORTH SEA WIND POWER HUB (EU, UK, AND NORWAY)	A large-scale offshore wind and hydrogen production project funded through a mix of EU grants, private investments, and energy sale revenues.	Increased cross-border energy integration and reduced dependency on fossil fuels.
H2 ENERGY EUROPE (SWITZERLAND & GERMANY)	A hydrogen production and distribution network co-financed by public funding, private investors, and partnerships with local businesses.	Expansion of hydrogen refueling stations and greater industry adoption.
H21 LEEDS CITY GATE (UK)	A hydrogen heating initiative in the UK financed by a combination of government funding, energy company investments, and private sector loans.	A scalable model for transitioning natural gas networks to hydrogen
WUNSIEDEL GREEN HYDROGEN PLANT	The project, led by Siemens, involves an 8.75 MW electrolyzer producing approximately 1,350 tons of hydrogen annually. Funding was sourced from Siemens Financial Services, local utility company SWW Wunsiedel GmbH, and additional private investors.	Financial resilience: it reduces dependence on a single funding source, enhancing financial stability. Risk mitigation: it distributes financial risk across multiple stakeholders. Enhanced credibility: it attracts a broader range of investors through demonstrated commitment from diverse parties.
Hy2B Hydrogen Cluster (Pfeffenhausen, Bavaria)	Regional hydrogen cluster with a grid-serving electrolyser at the national hydrogen technology centre, supplying RFNBO green H ₂ to mobility and industrial users within ~300 km.	Created a hybrid-owned regional cluster (companies, districts, citizen co-ops); positioned as a HyPerformer lighthouse; offers a replicable model for regional hydrogen production with strong local anchoring.
North Adriatic Hydrogen Valley (Slovenia - Croatia - FVG, Italy)	Europe's first fully transnational hydrogen valley, funded by Horizon Europe and led by HSE, bringing together 37 partners from Slovenia, Croatia and Italy's Friuli Venezia Giulia region. NAHV is built around 17 industrial testbed projects covering the full renewable hydrogen value chain - production from RES, storage, distribution and use in hard-to-abate industries, energy and land/maritime transport - with an expected output of >5,000 t/year of H ₂ and at least 20% traded cross-border.	Establishes a cross-border hydrogen ecosystem and primary regional H ₂ market in the North Adriatic, positioning the macro-region as an EU lighthouse for large-scale hydrogen valleys. It delivers concrete pilot investments and governance structures that can be replicated in at least five additional hydrogen valleys, strengthening regional energy security and industrial decarbonisation across Central and South-Eastern Europe.
Hydrogen Park - Porto Marghera (VE)	Consortial company created in 2003 to develop a hydrogen district in Porto Marghera, transforming a former petrochemical area into an innovation hub for hydrogen. Hydrogen Park brings	Established a long-term hydrogen governance and innovation platform in Porto Marghera; delivered multiple demonstration projects (e.g.



	<p>together major industrial players (e.g. Eni, Edison, Sapio, Decal), Confindustria Venezia and other firms to design and implement demo projects on hydrogen production, storage, distribution and use in industry and mobility. Today it is a key partner of the North Adriatic Sea Port Authority and Sapio in the “Hydrogen Valley Venezia”, including new PNRR-funded green hydrogen plants on brownfield sites.</p>	<p>hydrogen power plant at Fusina, early H₂ demos) and now underpins the evolution towards a full Hydrogen Valley Venezia. The hub strengthens the port-industry ecosystem, accelerates permitting and access to PNRR funds, and positions Porto Marghera as a strategic Italian green hydrogen hub.</p>
<p>Upper Austria Hydrogen Initiative</p>	<p>Regional initiative of Land Oberösterreich to build a hydrogen region around the “OÖ Wasserstoff-Offensive 2030”. It combines three pillars: (1) an OÖ Hydrogen Research Centre in Wels run by FH Oberösterreich, (2) the OÖ Hydrogen Network, a strategy board and network of companies and research institutions coordinated by Business Upper Austria, and (3) a dedicated funding call (“Future Energy Technologies”) to support H₂ R&D and pilot projects. The initiative frames and connects lighthouse projects such as the first hydrogen pipeline between Linz and Sattledt, underground H₂ storage concepts and industrial pilots (Hy4Smelt, Green Ammonia Linz, H₂ hubs).</p>	<p>Has established Upper Austria as one of Austria’s leading hydrogen regions: a permanent hydrogen research centre, a structured hydrogen network for industry and research, and a portfolio of flagship projects along the whole value chain (production, pipelines, storage, industrial use). It provides a long-term governance and funding framework that aligns regional government, city of Linz, utilities (LINZ AG, Energie AG, VERBUND) and large industries around a common H₂ roadmap.</p>
<p>PKP Cargo Hydrogen Trains</p>	<p>Series of industrial cooperation agreements to develop hydrogen-powered locomotives and freight wagons for rail freight in Poland. Since 2018 PKP Cargo and JSW have been working on the use of hydrogen (from coking gas) for shunting locomotives and wagons, later joined by rolling-stock manufacturer H. Cegielski-FPS and supported by the Industrial Development Agency. In 2021 PKP Cargo, Grupa Azoty and PESA signed a further alliance to develop zero-emission freight rail using hydrogen traction, hydrogen logistics and refuelling solutions.</p>	<p>Has created a structured industrial platform for Polish hydrogen freight traction, defining technical options (use of hydrogen from coking gas, focus on shunting first), development paths for new rolling stock and hydrogen logistics, and positioning PKP Cargo as a future large buyer of domestic hydrogen locomotives. It provides the R&D and partnership basis on which concrete pilot locomotives and services can be deployed in the coming years.</p>
<p>Mazovian Hydrogen Valley (Mazowiecka Dolina Wodorowa)</p>	<p>Regional hydrogen valley / cluster in central Poland led by ORLEN, created through letters of intent and cluster agreements with >50 partners from business, research, finance and public institutions. The valley aims to build a full hydrogen value chain in the Mazovia region - production (including hubs in Płock and Ostrołęka), storage, distribution and use in transport, energy, municipal services and</p>	<p>Establishes a structured governance and cooperation platform for hydrogen in the Mazovia region, aligning ORLEN’s industrial projects (e.g. hydrogen hubs, refuelling stations, prototype locomotives) with universities, local authorities and infrastructure operators. It anchors EU-funded projects such as HySPARK and</p>



	agriculture - and to coordinate R&D projects, skills development (Hydrogen Academy) and regulatory support.	positions Mazovia as a key Polish hydrogen region within the national network of hydrogen valleys.
Brno Hydrogen Public Transport	City-led initiative to decarbonise public transport using locally produced hydrogen. Under the planned H2vBrno association, the City of Brno, Teplárny Brno, the Brno Transport Company (DPMB), SAKO and Brno University of Technology coordinate a project to produce up to ~600 t/year of (partly renewable) hydrogen from municipal energy sources. The hydrogen is intended primarily for emission-free urban buses and municipal collection vehicles, in line with the Czech hydrogen strategy and in cooperation with the national Hydrogen Mobility Initiative.	Has created a formal hydrogen cluster (H2vBrno) and a working group linking city, municipal companies, academia and private partners; completed feasibility work on siting an electrolyser at Teplárny Brno for bus supply; carried out early hydrogen-bus demonstrations and positioned Brno as a Czech frontrunner for hydrogen-powered public transport and broader urban energy self-sufficiency.

Table 19 - Examples of hybrid funding projects

11.12. Annex 12: RACI Matrix

Task	Lead partner	Region / municipality	TSO / infra operator	Industrial off-taker	Community / NGO	University
Stakeholder mapping	R	C	C	C	C	A
Local adaptation plan	A	R	C	C	I	C
M&E plan (KPI/baseline)	R	C	C	C	I	A
Risk register (incl. DNSH)	A	C	R	C	C	C
Community engagement plan	C	A	I	I	R	C

Table 20 - SHs' RACI

11.13. Annex 13: Checklist to prioritise Stakeholders

1. Is this stakeholder critical for permitting or regulation?
2. Can this stakeholder provide anchor demand or infrastructure? (e.g. large fleet operator, refinery, steel plant, port, railway)
3. Does this actor have strong convening power or political influence? (e.g. region, metropolitan authority, national agency)
4. Is this actor directly affected socially or economically? (e.g. residents near sites, coal regions in transition, property owners)



5. Can this stakeholder mobilise local capital or knowledge? (cooperatives, energy communities, universities, hydrogen clusters)

If yes to Q1-3 → classify as “manage closely”.

If yes primarily to Q4-5 → “keep satisfied” or “keep informed”, but with special attention to social acceptance (publics may move quickly from “monitor” to “manage closely” if conflicts arise)

11.14. Annex 14: “Job-to-be-done” framework

1. Identify unmet customer needs.

Ask yourself the following questions:

- What pain points do my customers have in common?
- What do they currently lack?
- What challenges exist for them?

2. Determine customers’ desired outcomes.

Without reference to the products or solutions you currently provide, complete the following phrases as though you were the customer:

- Help me do _____.
- Help me to avoid _____.
- I need to _____.

For example, “Help me save time in the morning” or “I need to take more clothes when I travel” articulate desires and could lead to product ideas such as an app for scheduling morning routines or a carry-on suitcase with more storage compartments.

You may find it helpful to ask customers and prospects to complete these phrases so that you can gather a variety of jobs-to-be-done insights.

3. Answer key JTBD questions.

- What does a customer want to achieve in a particular circumstance?
- What could help the customer achieve this, such as resources, tools, or information?
- What constraints keep the customer from achieving the desired outcome, such as not having access to needed resources or doubting their abilities?
- What are the functional aspects of what they need done? What will it help them do, such as complete a task more efficiently or avoid tasks they don’t want to do?
- What social or emotional factors correspond to a customer’s objective, including how they want to feel and have others perceive them?

4. Create a job to be done statement.

Using the ideas you gathered in steps 1, 2, and 3, construct a jobs to be done statement that can lead to more product innovations. Draw from the template and music streaming example below.

11.15. Annex 15: Customer persona template

Customer template



2. Persona Identification

- Name / Label: (e.g., “Industrial Off-taker - Fertilizer Producer”, “Heavy-Duty Fleet Operator”, “Port Authority”, “Renewable Hydrogen Developer”)
- Sector / Sub-sector: (Industry, Transport, Logistics, Energy, Public Authority, Technology Provider)
- Geographical scope: (Region, national, EU corridor)
- Value-chain position: (Producer, distributor, infrastructure operator, end-user, enabler)

3. Organisation Profile

- Company size: (SME, mid-cap, large industrial, multinational, public agency)
- Core activities: (Manufacturing, refining, logistics operations, fleet management, energy production, network operation)
- Existing energy mix: (Gas-heavy, electricity-dominant, diesel fleet, mixed fuels)
- Current hydrogen exposure:
 - o None
 - o Early exploration
 - o Piloting
 - o Commercial adoption

4. Strategic Drivers

- Decarbonisation obligations / targets: (Corporate net-zero goals, ETS exposure, ESG commitments)
- Operational pressures: (High fuel cost, emission compliance risk, energy security concerns)
- Innovation objectives: (Diversify fuels, adopt new tech, improve efficiency)
- Competitive pressures: (Peers adopting H₂? Need to maintain green positioning?)

5. Pain Points & Barriers

- Technical barriers: (Storage constraints, lack of H₂-ready equipment, integration with existing assets)
- Economic barriers: (High CAPEX/OPEX, uncertain ROI, volatile energy prices)
- Infrastructure barriers: (No nearby refuelling station, no pipeline, grid limitations)
- Regulatory barriers: (Permitting time, unclear incentives, certification requirements)
- Organisational barriers: (Lack of skilled workforce, internal resistance, safety concerns)

6. Desired Outcomes

- Primary goals: (Lower emissions, diversify energy supply, reduce fuel cost, access subsidies)
- Operational benefits sought: (Higher efficiency, stable long-term contracts, better energy resilience)
- Business transformation goals: (Green value chain, new product lines, better public image)

7. Hydrogen Use Case(s)

- Type of hydrogen needed:
 - o Green



- Low-carbon (blue)
- Any clean hydrogen
- Typical demand profile: (*kg/day, MW electrolyser equivalent, variability of consumption*)
- End-use application:
 - Industry (*heat, feedstock, processes*)
 - Mobility (*heavy-duty trucks, buses, rail, port equipment*)
 - Power (*H₂-ready turbines, storage*)
 - Blending (*grid injection*)

8. Partnership Preferences

- Preferred partners: (*Utilities, OEMs, technology suppliers, gas TSOs/DSOs, research institutes*)
- Need for public authorities: (*Permitting, zoning, infrastructure co-investment, subsidies*)
- Financing expectations: (*Equity, debt, grants, blended finance*)
- Expectations from suppliers: (*Reliability, scalability, service contracts, guarantees*)

9. Key Metrics (KPIs)

- Cost per kg or per MWh (target)
- Emission reductions achieved
- Operational savings
- Reliability / uptime requirements
- Safety standards and compliance metrics



11.16. Annex 16: Value Proposition Canva template and explanation

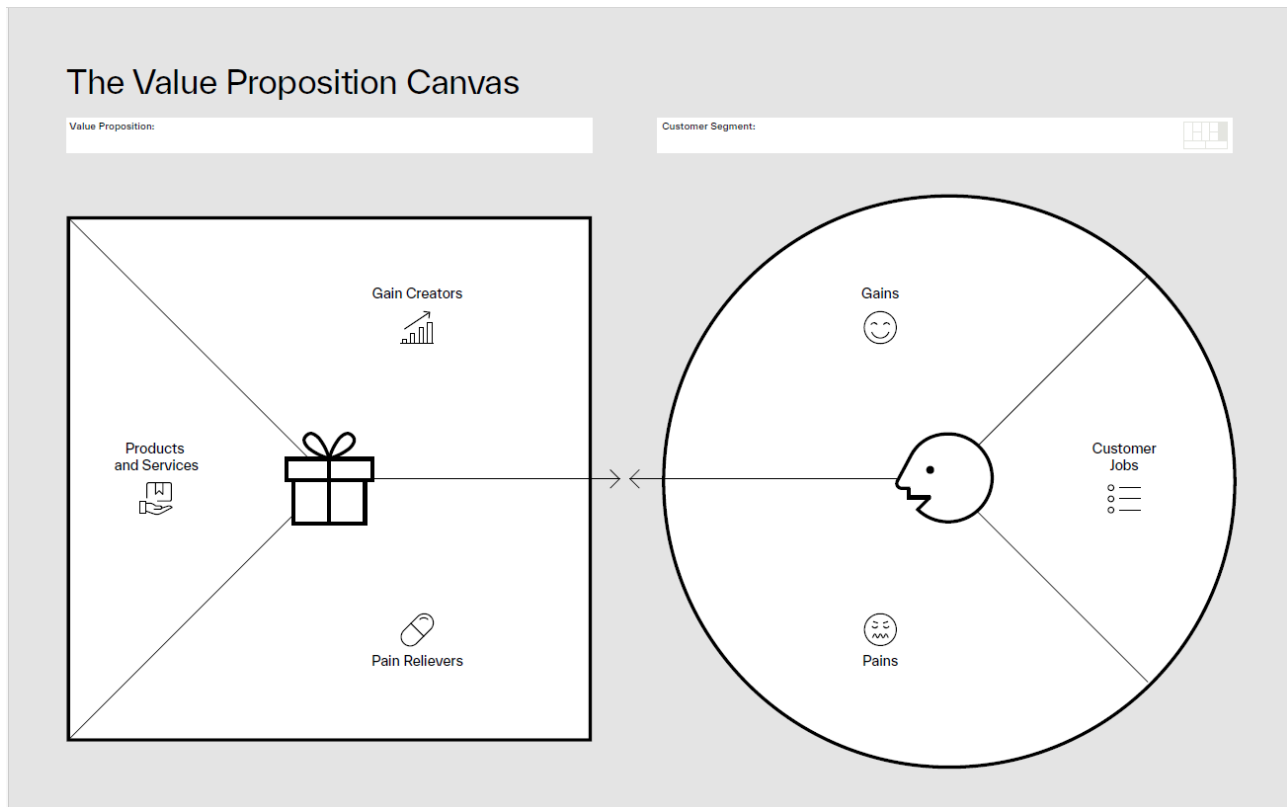


Figure 11 - Value proposition Canva template and explanation

- **The circle: Customer profile:** Traditionally, the introduction to the canvas begins with the right-hand side representing the customer profile. The circle is divided into three parts where tasks and expectations that customers will fulfil, as well as the positive and negative experiences associated with them. You are not concerned with the product at this stage, but only with the end user's challenges.
 - o **Customer jobs:** what customers are trying to accomplish in their work and daily lives: activities they are trying to perform and complete, problems they are trying to solve, or needs they are trying to satisfy. In this way, you refine the customer segment from an emotional (preferences, popularity), social (reputation, sense of duty) and functional (feasibility) point of view.
 - o **Pains:** anything that bothers your customers before, during and after attempting to perform a job, or that simply prevents them from completing it. This term also includes risks, i.e. potential negative outcomes resulting from performing a job poorly or not performing it at all. Based on the above, it is possible to identify which negative/frustrating results/experiences could be associated with the jobs described. Since the perception of negative experiences differs across diverse user categories, it is best to cover as many difficulties as possible.
 - o Gains are the outcomes and benefits customers want; they can be necessary (without which a solution would not work), expected (essential), desired (beyond what we expect) or unexpected (beyond expectations). It should be noted that difficulties and gains are not opposing concepts.



- The square: the value map: They correspond to the relevant section of the customer profile. Here we will deal with the product. The focus is on features, functionality and benefits that can not only attract customers, but also meet their needs in the right way.
 - o **Products and services:** offers in terms of products or services.
 - o **Pain relievers:** capability product's ability to solve defined problems. It is not necessary to describe in detail how the difficulties are alleviated.
 - o **Gain creators:** what extra value your product/service will provide to customers. The idea is to offer something new and unique to make the customer experience not only better but also exciting.

11.17. Annex 17: Risk-Impact Template

	Impact: Low	Impact: Medium	Impact: High
Likelihood: High	Medium Risk	High Risk	High Risk (Critical)
Likelihood: Medium	Low Risk	Medium Risk	High Risk
Likelihood: Low	Low Risk	Low Risk	Medium Risk

Table 21 - Risk-Impact Template

11.18. Annex 18: Adapted Business Model Canvas template for hydrogen hubs

Key Partners Value Propositions Customer Segments Policy & Regulatory Framework	Key Activities Customer Relationships Cost Structure Sustainability & Territorial Impact	Key Resources Channels Revenue Streams Risk & Resilience

Table 22 - Adapted Business Model Canvas template for hydrogen hubs

11.19. Annex 19: HAZID template

Severity code	Consequences				Probability			
	Personnel	Assets	Environment	Reputation	Unlikely	Has occurred	Has occurred within the operating company	Occurs several time in the year
Minimal								
Low								
Medium								
High								
Very High								

Table 23 - HAZID Template



11.20. Annex 20: HAZOP Template

Deviation	Possible causes	Consequence	Assessment for	Risk Ranking (Initial)			Existing controls	Risk Ranking (Current)			Current Risk	Recommendations	Action Party	Remarks
				L	S	R		L	S	R				

Table 24 - HAZOP Template

11.21. Annex 21: CBA Cost Benefit Analysis

COST CATEGORY

Cost Category	Description	Value	Unit	Notes
CAPEX	Electrolysers, pipelines, HRS, storage		M€	Include contingencies
OPEX	Energy, maintenance, labour		M€/year	
Replacement costs	Stack replacement, compressors		€	Lifetime assumptions
Environmental costs	Residual emissions, externalities		€/tCO ₂	Only if applicable
Decommissioning	End-of-life dismantling		€	

Table 25 - Cost categories in CBA

BENEFIT CATEGORIES

Benefit Category	Description	Value	Unit
GHG reduction	CO ₂ avoided vs fossil baseline	tCO ₂ /year	Converted using €/tCO ₂ social cost
Air quality benefits	NO _x / PM reductions	€	Use damage cost factors
Fuel cost savings	vs diesel/NG	€/year	For mobility or industry
Energy diversification	Security of supply	Qualitative or €	
Job creation	Direct/indirect employment	FTE	
Innovation spillovers	Tech learning, patents	Qualitative or €	
Regional development	GDP impact, local value added	€	

Table 26 - Benefit categories in CBA

ECONOMIC INDICATORS

Indicator	Formula / Source	Value
Net Present Value (NPV)	$\Sigma(\text{Benefits} - \text{Costs})$ discounted	
Benefit-Cost Ratio (BCR)	Present value of benefits / costs	
Internal Rate of Return (IRR)	Discount rate where NPV=0	
Payback Period	Years to recover CAPEX	

Table 27 - Economic indicators in CBA



11.22. Annex 22: MCA Multi Criteria Analysis

MCA CRITERIA FRAMEWORK

Criterion Category	Criterion	Description	Unit / Scale	Weight (0-1)
Technical	Efficiency	Electrolyser/system efficiency	%	
	Reliability	Availability, downtime	%	
	Scalability	Ability to expand capacity	Qualitative (1-5)	
Economic	CAPEX	Total initial investment	€/kW or M€	
	OPEX	Operating costs	€/kg H ₂ or M€/year	
	LCOH	Levelised cost of hydrogen	€/kg H ₂	
Environmental	GHG intensity	gCO ₂ eq per kg H ₂		
	Air quality	Local air pollutants reduction	Qualitative (1-5)	
Social	Job creation	Estimated FTEs	Number	
	Public acceptance	Social acceptance score	Qualitative (1-5)	
Policy/Regulatory	Permitting complexity	Ease of permitting	Qualitative (1-5)	
	Alignment with targets	Fit with hydrogen/regional plans	Qualitative (1-5)	

Table 28 - MCA-Multi Criteria Framework

SCORING TABLE

Scenario / Option	Efficiency	CAPEX	OPEX	LCOH	GHG intensity	Public acceptance	...	Weighted score
Option A	4	3	2	3	5	4	...	
Option B	5	2	4	4	3	3	...	

Table 29 - Scoring table in MCA

11.23. Annex 23: LCA - Life Cycle Assessment

Element	Description
Functional unit	1 kg of hydrogen delivered at use site
System boundary	Cradle-to-gate or well-to-wheel (include: RES production, electrolysis/SMR, compression, storage, transport, dispensing)
Allocation rules	Energy or mass-based allocation for co-products
Impact categories	GHG, energy use, water use, land use, acidification, eutrophication, resource depletion

Table 30 - Life-Cycle Assessment

LCI - LYFE-CICLE INVENTORY

Process step	Inputs	Unit	Data source
Renewable electricity	kWh/kg H ₂		Ecoinvent, national grid mix
Water electrolysis	Water use	litres/kg H ₂	
Compression	Electricity	kWh/kg H ₂	
Storage	Material use	kg material	
Transport	Distance travelled	km	
SMR+CCS (if included)	Natural gas, captured CO ₂	kg	



Table 31 - Lyfe-Cicle inventory

IMPACT ASSESSMENT

Impact Category	Method	Result	Unit
GHG emissions	IPCC 100y	gCO ₂ eq/kg H ₂	
Primary energy demand	CED	MJ/kg H ₂	
Water footprint	ISO 14046	litres/kg H ₂	
Land use	various	m ² /kg H ₂	
Resource depletion	CML		

Table 32 - Impact assessment in LCA





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