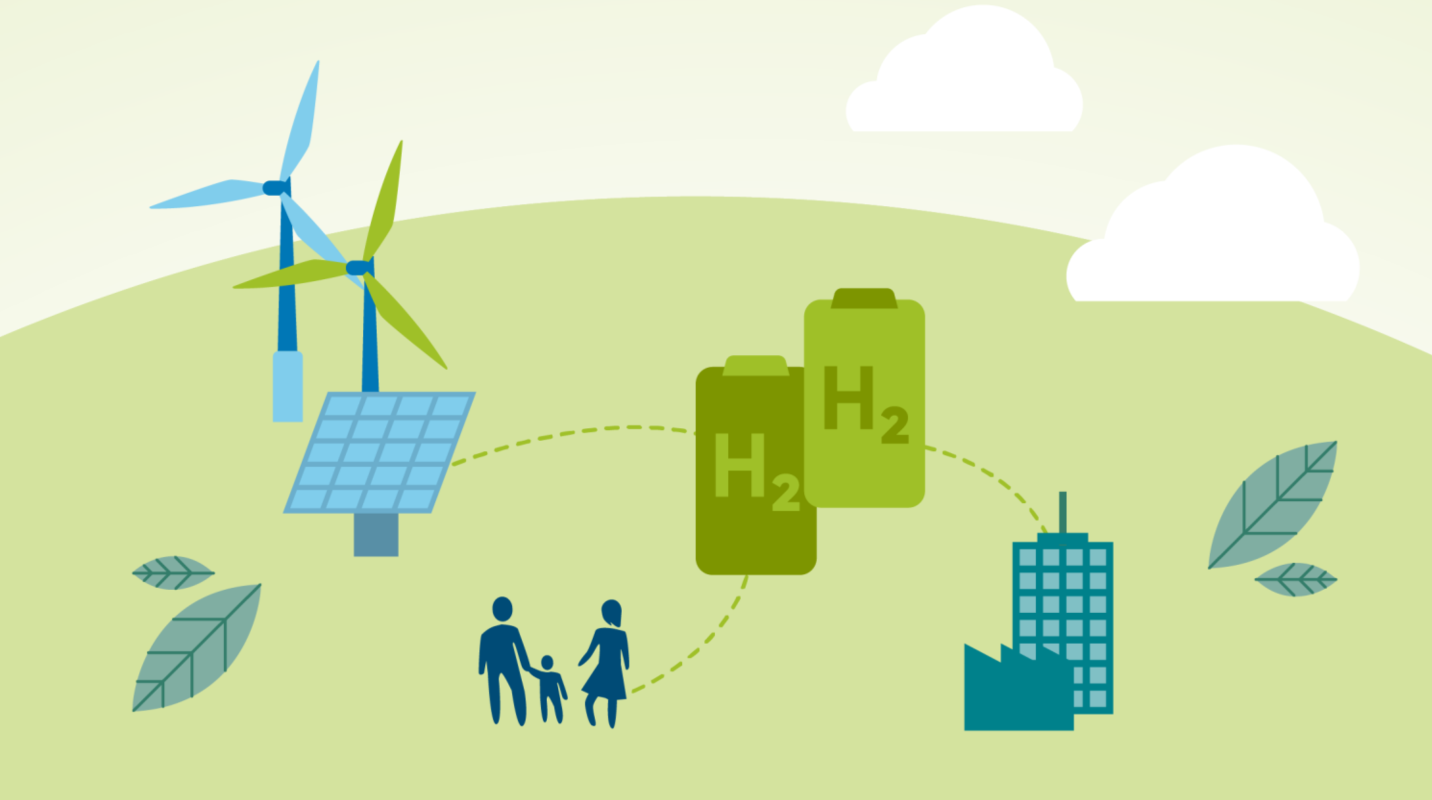
Enhancing Offtake in the European Hydrogen Market

Financing Methods and Support Mechanisms



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The Green Hydrogen Business Alliance (H2BA) produced this report between March and April 2025 on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ) in cooperation with GET.invest.

H2BA is implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) and supports the sustainable and inclusive international market ramp-up of green hydrogen and Power-to-X.

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Abbreviations

ADEME	French Environment and Energy Management Agency
AMIS	Advanced Manufacturing and Infrastructure Stream
CAPEX	Capital expenditure
CBAM	Carbon Border Adjustment Mechanism
CBAM	Carbon Border Adjustment Mechanism
CCS	Carbon capture & storage
CDC	The Hydrogen Infrastructure Fund (co-managed by CDC and ADEME)
CfD	contract-for-difference
CoLab	Collaboration Lab
DOE	U.S. Department of Energy's
EPC	Engineering, Procurement, and Construction
EU	European Union
EUR	Europe
FC	Fuel Cell
FCEV	Fuel Cell Electric Vehicle
FIDs	Final Investment Decisions
GH2	Green Hydrogen
GHG	Greenhouse Gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
H_2	Hydrogen
H2Hubs	Hydrogen Hubs
H2Hubs	Hydrogen Hubs
H2V	Hydrogen Valleys Initiative
HARs	Projects compete for HPCs in regular allocation rounds
HPAs	Hydrogen Purchase Agreements

HPBM	Hydrogen Production Business Model
HPBM	Hydrogen Production Business Model
HPCs	Hydrogen Production Contracts
HyA-MMED	Hydrogen for the Mediterranean region
IPCEI	Important Projects of Common European Interest
LCHA	Low Carbon Hydrogen Agreement
LCs	Letters of Credit
LH_2	Liquid Hydrogen
LH2	Liquefied Hydrogen
LNG	Liquefied Natural Gas
LNG	Liquefied Natural Gas
LoCs	Letters of Credit
LOHC	Liquid organic hydrogen carriers
MITECO	The Ministry for Ecological Transition and the Demographic Challenge
NH_3	Ammonia
NZHF	Net Zero Hydrogen Fund
PPA	Power Purchase Agreement
PPAs	Power purchase agreements
PPPs	Public-private partnerships
PtX	Power-to-X
RED	Renewable Energy Directive
RED II	EU Renewable Energy Directive II
RED III	EU Renewable Energy Directive III
REDII	Renewable Energy Directive Recast
REGO	Renewable Energy Guarantee of Origin
RFNBO	Renewable fuels of Non-Biological Origin
RFNBOs	Renewable Fuels of Non-Biological Origin

RSA	Republic of South Africa
SAF	Sustainable Aviation Fuel
SOEs	State-Owned Enterprise
SPAs	Sale-and-Purchase Agreements
UK	United Kingdom
UN	United Nations
WACC	Weighted Average Cost of Capital
WTO	World Trade Organisation
CCfDs	Carbon Contracts for Difference
OPEX	Operational Expenditures
CAPEX	Capital Expenditure
BaaS	Battery-as-a-Service
EaaS	Energy-as-a-Service
EV	Electric Vehicle
NH_3	Ammonia
CO_2	Carbon dioxide
ASUs	Air Separation Units
DAC	Direct Air Capture
PtX	Power-to-X
PtL	Power-to-Liquid
LOHCs	Liquid Organic Hydrogen Carriers
HCOOH	Formic Acid
PPPs	Public-private partnerships
R&D	Research and Development
H2Hubs	Hydrogen Hubs
WACC	Weighted Average Cost of Capital
LH2	Liquefied hydrogen

FIDs	Final Investment Decisions
RFNBOs	Renewable Fuels of Non-Biological Origin
LCHA	Low Carbon Hydrogen Agreement
CBAM	Carbon Border Adjustment Mechanism
PPAs	Power Purchase Agreements
PPPs	Public-Private Partnerships

Executive Summary

The development of a robust hydrogen offtake market is critical for Europe's decarbonization objectives, particularly in industries that are difficult to abate, such as steel, refining, chemicals, and heavy transport. While hydrogen production capacity continues to expand, the absence of long-term offtake agreements remains a significant barrier to financing and commercial deployment. Industrial buyers remain reluctant to commit to long-term contracts due to high costs, policy uncertainties, and concerns about future price volatility. This reluctance has resulted in a financing bottleneck, slowing the scale-up of hydrogen projects and limiting the speed of market development.

This report, developed under the Green Hydrogen Business Alliance Collaboration Lab (CoLab) initiative, examines the challenges associated with securing bankable hydrogen offtake agreements across the European market. It evaluates existing financial support mechanisms, assesses global best practices, and explores alternative contractual solutions that could encourage industrial buyers to enter into long-term purchase commitments. The ultimate goal is to provide practical recommendations that will support investment certainty and de-risk hydrogen projects, thereby accelerating the deployment of clean hydrogen infrastructure.

A key aspect of this study involves comparing hydrogen offtake models across different global markets, including Germany, France, the UK, the US, South Korea, Japan, China, and Spain. The analysis highlights key lessons that can inform the design of new European interventions aimed at improving the bankability of hydrogen projects.

Key Findings and Market Insights

The research underscores that the lack of standardized, scalable offtake agreements is a major constraint to securing project financing. Unlike renewable power purchase agreements (PPAs), which provide predictable revenue streams, hydrogen offtake agreements remain bespoke and often lack clear pricing benchmarks. The cost disparity between renewable hydrogen and fossil-based alternatives continues to deter potential buyers, particularly in industries where cost competitiveness is paramount. Moreover, uncertainties surrounding carbon pricing mechanisms, such as the EU Emissions Trading System and the Carbon Border Adjustment Mechanism (CBAM), have further slowed commitments from industrial users.

Different global markets have approached these challenges with varying degrees of intervention. Germany's H2Global auction system, for instance, provides price stability for producers while reselling hydrogen under shorter-term contracts, bridging the gap between production costs and market willingness to pay. In contrast, France has emphasized public-private partnerships (PPPs) and a contract-for-difference (CfD)-style model to stimulate demand. The UK's Hydrogen Production Business Model (HPBM) adopts a similar approach, ensuring revenue certainty for hydrogen producers. Meanwhile, the United States has pursued a more direct interventionist strategy through the Department of Energy's Hydrogen Hubs (H2Hubs) initiative, which aggregates regional demand and guarantees offtake. South Korea, Japan, and China have integrated hydrogen incentives into broader industrial policies, leveraging government-backed subsidies, corporate PPAs, and strategic procurement programs to scale up demand.

A major finding of this study is that Europe faces structural barriers that hinder the widespread adoption of long-term hydrogen offtake agreements.

Regulatory fragmentation across EU member states significantly hinders the development of a unified hydrogen market, creating inconsistencies in certification schemes, carbon pricing mechanisms, and support programs. For instance, while the Renewable Energy Directive (RED) sets a common framework, national interpretations vary considerably, leading to different criteria for defining "renewable" hydrogen and complicating cross-border trade. Carbon pricing mechanisms also differ widely, with some member states levying significantly higher carbon taxes than others, distorting the economic incentives for switching to green hydrogen. Furthermore, support programs for hydrogen production and consumption vary substantially in terms of eligibility criteria, funding levels, and administrative procedures, creating an uneven playing field for project developers and hindering the efficient allocation of resources across the EU. These inconsistencies add complexity and uncertainty to the market, deterring investment and slowing the transition to a hydrogen economy.

Infrastructure limitations, including the lack of large-scale hydrogen storage and dedicated pipeline networks, further complicate the establishment of cross-border offtake agreements. Additionally, the financial risks associated with offtake agreements—such as the creditworthiness of buyers and the need for volume flexibility—pose challenges for debt financing.

A review of international best practices suggests that hybrid financing solutions could play a critical role in addressing these issues. The EU's existing funding mechanisms, including the European Hydrogen Bank, primarily rely on competitive auctions, which may not provide sufficient revenue certainty for developers. In contrast, more structured approaches, such as US-style government-backed offtake agreements or UK-style CfD models, could complement the existing framework. Similarly, innovative solutions such as aggregated buyer consortia, sector-specific procurement guarantees, and hybrid CfD-PPA models could provide a more stable investment environment for hydrogen developers.

Proposed Interventions to Strengthen Hydrogen Offtake Agreements in Europe

In response to these findings, the report proposes a series of interventions aimed at improving the security and bankability of hydrogen offtake agreements. A key recommendation is the introduction of hybrid financing models that combine the stability of Contracts for Difference (CfDs) with the long-term purchasing commitments of Power Purchase Agreements (PPAs). This blended approach would offer price stability for producers while ensuring demand certainty from industrial buyers.

Another proposed intervention is the establishment of demand aggregation platforms and buyer consortia. These platforms would allow multiple buyers to pool their hydrogen demand, reducing counterparty risk and enabling project developers to secure more bankable contracts. Such models could be particularly effective in industrial clusters where hydrogen demand is fragmented across multiple users.

To encourage early adopters, the report also suggests the introduction of capacity-based incentives. These would provide financial support to industrial users willing to commit to renewable hydrogen adoption, similar to the capacity payment mechanisms used in electricity markets. Sector-specific offtake guarantees, targeting industries such as steel, chemicals, and aviation, could further enhance market stability by aligning hydrogen procurement with long-term decarbonization objectives.

A further innovative approach explored in the report is the development of hydrogen-as-a-service business models. Under this framework, hydrogen suppliers would lease infrastructure and provide hydrogen as a managed service, reducing the upfront capital requirements for industrial users and expanding access to the hydrogen economy.

Beyond these demand-side interventions, the report highlights the need for enhanced credit support mechanisms. Government-backed guarantees and risk-sharing frameworks could help mitigate offtaker credit risk, making it easier for developers to secure financing and for lenders to structure debt packages that align with long-term project economics.

Conclusion

The ability to secure long-term, bankable offtake agreements remains one of the most significant barriers to scaling up Europe's hydrogen market. This report has examined the structural challenges facing hydrogen offtake, reviewed global best practices, and proposed a set of targeted interventions that could enhance investment certainty. By leveraging hybrid financing models, buyer aggregation platforms, sector-specific guarantees, and innovative risk mitigation tools, Europe can create a more investable hydrogen ecosystem.

The recommendations set out in this report provide a pathway for industry engagement and policy action. Through coordinated efforts between policymakers, financial institutions, and hydrogen stakeholders, these solutions can be refined and implemented in a way that accelerates market growth while ensuring financial viability for both producers and consumers. The forthcoming H_2BA Collaboration Lab (CoLab) workshops will serve as a key platform for advancing these discussions and shaping the future of hydrogen offtake in Europe.

1. Introduction

The Green Hydrogen Business Alliance's Collaboration Lab (CoLab) is a process aimed at identifying key bottlenecks and developing target-ed solutions to foster investment in green hydrogen projects across the value chain in partner countries. Taking a holistic approach, the CoLab Process brings together companies and market players from partner countries and Europe to address market-relevant and economically viable challenges. The ultimate goal is to establish joint ventures or targeted partnerships, whether private-sector or public-private, to close the identified gaps and accelerate the adoption of green hydrogen technologies.

On the demand side, the lack of incentives further stifles market growth. While current efforts predominantly focus on production support, the absence of demand-side incentives limits consumer and business uptake of green hydrogen. Consumers and businesses need assurance and motivation to switch to green hydrogen, which requires comprehensive and balanced policy interventions that address both supply and demand.

Objectives of the Report

The rapid deployment of green hydrogen is a critical pillar of Europe's decarbonization strategy, enabling deep emissions reductions in hard-to-abate sectors such as steel, chemicals, refining, heavy transport, and power generation. However, despite the momentum in hydrogen production investments, offtake agreements remain a key bottleneck in scaling up the market. The reluctance of buyers to commit to long-term hydrogen purchase agreements—due to high costs, policy uncertainty, and price volatility—poses a fundamental challenge to project bankability.

This report aims to identify, analyze, and propose solutions for enhancing offtake in the European hydrogen market by:

- Providing a comprehensive overview of existing and soon-to-be-implemented financial support mechanisms for hydrogen offtakers.
- Evaluating successful offtake models globally, including government-backed contracts, auction mechanisms, and industrial cluster initiatives.
- Identifying new, practical demand-side financing and contractual solutions that could be adopted to stimulate long-term offtake commitments.
- Facilitating an industry-wide discussion with potential offtakers, policymakers, and financiers to align expectations and improve contractual structures.
- Developing actionable recommendations to inform the EU and international donors on innovative financial and policy interventions.

In summary, this report aims to provide a comprehensive analysis of the challenges associated with securing long-term hydrogen offtake agreements in the European market, focusing on the barriers faced by project developers, industrial offtakers, and financiers. As the hydrogen market evolves, a lack of established market structures, pricing benchmarks, and standardized contracting models continues to impede investment decisions and the bankability of projects. Beyond diagnosing these challenges, the report will explore enhancements to existing market practices—such as refining contractual structures, improving risk allocation, and leveraging financial support mechanisms—to increase confidence in hydrogen offtake arrangements. Additionally, it will propose new potential solutions, drawing on global best practices, financial innovation, and emerging policy interventions, with a view to informing discussions in the upcoming H_2BA Collaboration Lab (CoLab) sessions later this year. These sessions will serve as a platform to refine, stress-test, and align industry-driven solutions with the needs of both hydrogen producers and offtakers, ultimately contributing to the development of a more investable and scalable European hydrogen market.

2. Scope and Methodology

The methodology follows a three-step approach:

1. **Problem Definition** (Session 1 – November 2023, Hamburg): The first CoLab session identified the lack of hydrogen PPAs and offtake contracts as a primary barrier due to the significant price gap between green hydrogen and fossil-based alternatives.
2. **Solution Development** (Session 2 – March 2024, TBD): This session will engage potential hydrogen offtakers to explore viable demand-side support mechanisms for hydrogen and its derivatives, considering sector-specific needs.
3. **Refinement and Policy Recommendations** (Session 3 – Post-March 2024): The outcomes from Session 2 will be compiled into a final report and presented to EU institutions, GET.pro, and other donors, offering concrete policy recommendations.

The analysis contained in this report is based on:

- A review of existing and announced financial support mechanisms across Europe, the US, and key global hydrogen markets.
- Case studies of successful hydrogen offtake agreements and contractual structures, including H2Global, the UK's Low Carbon Hydrogen Agreement (LCHA), and the US DOE's H2Hubs model.
- Interviews and brainstorming sessions with private sector actors and financiers to propose new demand-side support instruments.

3. Importance of Hydrogen Market Development in Europe

Green hydrogen is increasingly seen as a strategic energy carrier that can accelerate the energy transition, reduce dependency on fossil fuels, and enhance energy security across Europe. Its large-scale deployment aligns with several key EU policy initiatives, including:

- **The European Green Deal and the Fit-for-55 package**, which target deep emissions reductions across energy-intensive industries.
- **The REPowerEU Plan**, which sets an ambitious goal of 10 million tonnes of domestic renewable hydrogen production and 10 million tonnes of imports by 2030.
- **The Hydrogen Bank and EU Innovation Fund**, which aim to de-risk early hydrogen projects and facilitate competitive bidding processes for hydrogen offtake.

Despite this strong policy push, the hydrogen market remains in a nascent stage, with very few bankable offtake agreements being signed. The fundamental challenges include cost competitiveness, market uncertainty, regulatory fragmentation and financing.

- **Cost Competitiveness**: Green hydrogen production remains significantly more expensive than fossil-based hydrogen. Without structured contracts for difference (CfDs) or other price-support mechanisms, offtakers are reluctant to commit to long-term agreements.
- **Market Uncertainty**: A lack of clear price discovery mechanisms and transparent benchmarks makes it difficult for buyers and sellers to agree on long-term contract structures.
- **Regulatory Fragmentation**: Differences in national hydrogen strategies, carbon pricing schemes, and certification requirements create uncertainty, deterring large-scale offtake commitments.
- **Financing and Risk Allocation**: Hydrogen projects struggle to secure bank debt financing, as commercial lenders view merchant hydrogen contracts as high-risk. The absence of creditworthy counterparties further exacerbates project risk.

3.1. Green Hydrogen as a Post-COVID Economic Recovery Tool

The post-COVID era has ushered in a renewed focus on green industrial policy and strategic energy investments to drive economic recovery, industrial competitiveness, and energy security. Green hydrogen is seen as a key driver of job creation and industrial competitiveness, particularly in regions with strong renewable energy resources and existing hydrogen infrastructure, as well as resilience against fossil fuel price volatility, reducing exposure to geopolitical risks and supply chain disruptions.

A just transition, ensuring that industries reliant on fossil fuels (such as refining and chemicals) can pivot toward cleaner alternatives without economic dislocation. Public and private financing institutions are therefore recalibrating their investment priorities to support hydrogen projects, but bankability remains a major constraint. This report seeks to address that gap by exploring structured offtake mechanisms and demand-side financing models that can unlock long-term purchase commitments and sustainable investment flows.

3.2. Alignment with UN Sustainable Development Goals (SDGs)

Scaling up green hydrogen is not only a climate imperative but also contributes to several UN Sustainable Development Goals (SDGs):

- **SDG 7** – Affordable and Clean Energy: Enabling renewable-based hydrogen production reduces reliance on fossil fuels and supports energy system decarbonization.
- **SDG 9** – Industry, Innovation, and Infrastructure: Supporting the development of hydrogen clusters and industrial hubs fosters innovation and technology deployment.
- **SDG 13** – Climate Action: Hydrogen serves as a key decarbonization tool for hard-to-abate sectors, ensuring emissions reductions in line with global climate targets.

4. Context and Challenges in the Hydrogen Offtake Market

4.1. The Role of Offtakers in the Hydrogen Value Chain

Offtakers play a critical role in the development and commercialization of the hydrogen economy, serving as the key demand drivers that enable hydrogen producers to secure financing and scale operations. In a nascent market where production costs remain high and price discovery is limited, securing creditworthy offtakers through long-term purchase agreements is essential for de-risking projects and ensuring financial viability.

Industrial players in sectors such as steel, refining, chemicals, and heavy transport represent the primary offtakers, as they seek to decarbonize operations and transition away from fossil-based hydrogen.

However, despite increasing regulatory pressure and ambitious carbon reduction targets, many potential offtakers remain reluctant to commit to binding agreements due to concerns over price volatility, supply security, and the lack of clear financial incentives.

The absence of standardized offtake structures, coupled with regional variations in subsidy mechanisms, further complicates contractual negotiations and limits market liquidity. As hydrogen markets mature, offtakers will need to assume a more proactive role in shaping contract structures that align with their operational needs while providing sufficient revenue certainty to attract investment.

The evolution of the power purchase agreement (PPA) market in renewable energy offers useful parallels, demonstrating how mechanisms such as price floors, indexed pricing models, and government-backed contracts for difference (CfDs) can create bankable revenue streams. For hydrogen, innovative solutions such as government-supported offtake programs (e.g., H2Global in Germany) and auction-based procurement models are emerging as potential enablers of demand growth.

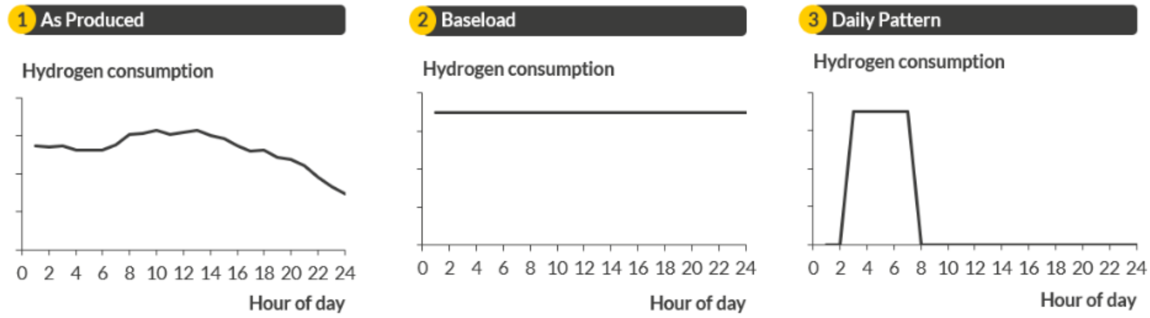
Additionally, industrial clusters and co-located hydrogen hubs present an opportunity for coordinated offtake aggregation, reducing offtaker risk by distributing supply across multiple consumers. Establishing a robust hydrogen offtake market will require a combination of commercial innovation, regulatory alignment, and financial risk mitigation mechanisms, all of which are explored further in this report.

4.2. Green Hydrogen Use cases (Offtakers)

4.2.1. Load profiles of different types of offtakers

The load profile is also a key consideration when segmenting the market for offtake arrangements.

Figure 1: Required offtake volumes & load factor profiles



Source: Aurora Energy 2024

Many offtakers require a specific hydrogen load factor profile in order to meet their own process requirements. Standard offtake profiles may include the following requirements:

- As produced: Here, the end-user can offtake hydrogen during the periods where renewable energy is available. Typically, these offtakers would be expected to have an alternative source of hydrogen available (such as grey hydrogen) or would have sufficient onsite storage capacity to balance their own requirements.
- Baseload: Here, the end-user requires a constant offtake, typically to allow a continuous industrial process to take place. Meeting a baseload profile either requires the electrolyser to utilise grid electricity in periods where renewables are not generating, which may impact the ability to meet renewable or low-carbon hydrogen standards, or the producer must have access to storage in order to smooth the offtake profile.
- Daily pattern: Here, the end-user has a consistent offtake requirement at a set frequency. This may be for use in transports where heavy duty vehicles are required to charge overnight. In this case, hydrogen storage is generally required in order to meet the required offtake profile.

The table below sets out the implications for contracting of the different load profiles:

Table 1: Load profiles

Load Profile	Characteristics	Use Case Type	Size (t Hydrogen)	Business Stability
As Produced	Variable intake based on renewable energy availability; requires backup systems or storage; suitable for processes that can be ramped up/down	Chemical manufacturers with flexible production schedules; green ammonia production facilities; industrial gas companies with existing storage infrastructure; hydrogen refueling stations with large storage capacity; metal powder production facilities	Typically, medium to large scale (100-500 t per year)	Short-term variable demand, depending on renewable generation availability

Baseload	Constant 24/7 demand; critical for continuous industrial processes; requires reliable supply infrastructure	Oil refineries (hydrocracking, desulfurization); steel manufacturing (direct reduction of iron); glass manufacturing; continuous chemical processing plants; food processing (hydrogenation of oils)	Large scale (>500 t per year)	Long-term stable demand with contractual commitments
Daily Pattern	Predictable peaks and troughs; often aligned with transportation schedules; storage requirements are more predictable	Heavy-duty vehicle fleets with scheduled routes; bus depots with overnight refueling; port operations with scheduled vessel arrivals; warehouse operations with specific shift patterns; mining operations with scheduled equipment maintenance	Medium to large scale (100-500 t per year)	Medium-term stable demand with some variability based on fleet size and operational shifts
Mixed Profiles	Combination of baseload, daily patterns, and as-produced hydrogen usage within the same facility	Large industrial parks integrating different processes; multi-sector industrial clusters with shared hydrogen infrastructure	Large scale (>500 t per year)	Combination of stable baseload demand with elements of flexibility for secondary operations

As the offtaker type, requirements and use cases vary enormously and unlike the electricity generation industry, do not lend themselves to a uniform or single offtake solution, one eeds to considers adapting offtake arrangements for different use cases to make sure all use cases can find the appropriate offtake solutions.

The table below sets out the key sectors and the different use cases and hence offtake arrangements:

Table 2: Offtaker Taxonomy

Load Profile	Characteristics	Use Case Type	Size (t Hydrogen)	Business Stability
As Produced	Variable intake based on renewable energy availability; requires backup systems or storage; suitable for processes that can be ramped up/down	Chemical manufacturers with flexible production schedules; green ammonia production facilities; industrial gas companies with existing storage infrastructure; hydrogen refueling stations with large storage capacity; metal powder production facilities	Typically, medium to large scale (100-500 t per year)	Short-term variable demand, depending on renewable generation availability
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Table 3: Offtaker Taxonomy

Type of Offtaker	Examples	Characteristics	Contractual Considerations	Challenges
Large Industrial Offtakers (Heavy Industry & Chemicals)	Steel production (e.g., ArcelorMittal, ThyssenKrupp), ammonia and fertilizer plants (Yara, CF Industries), refineries, chemical manufacturers	Large-scale, continuous hydrogen consumers with high energy demand. Hydrogen is used as a direct feedstock for industrial processes.	Long-term agreements (10-20 years) with price stability requirements. Indexed pricing linked to carbon pricing or natural gas benchmarks.	High infrastructure conversion costs. Dependent on strong policy incentives to compete with fossil-based alternatives.
Transportation and Mobility Sector	Hydrogen fuel cell trucks (Daimler, Volvo), rail transport (Alstom), shipping (Maersk), aviation (Airbus' hydrogen aircraft concept)	Requires hydrogen for mobility applications, either as gaseous hydrogen (fuel cells) or derivatives (ammonia for shipping, e-fuels for aviation).	Medium- to long-term contracts (5-15 years), subject to technological development and policy shifts. Delivery logistics to refueling stations and transport hubs are critical.	High cost of storage and refueling infrastructure. Uncertainty regarding adoption rates and regulatory support.
Power Generation and Grid Balancing	Gas turbine operators (Siemens Energy, GE), utilities integrating hydrogen storage	Hydrogen used for energy storage and as a substitute for natural gas in peaker plants or baseload applications. Demand is intermittent and dependent on grid balancing needs.	Shorter contract durations (5-10 years) due to evolving policy frameworks. Indexed pricing tied to electricity market fluctuations and carbon credits.	Uncertainty over regulatory recognition of hydrogen in power markets. Competing energy storage solutions such as batteries.
Emerging and Niche Applications	Data centers (Microsoft exploring hydrogen backup power), residential heating (hydrogen blending in gas grids), synthetic fuels	Early-stage adoption, typically part of pilot projects. Potential for long-term growth but currently small-scale.	Short-term contracts with high flexibility. May require supplier-side financing support due to early market risks.	Uncertain infrastructure development. Regulatory constraints and need for large-scale proof-of-concept projects.

Merchant and Trader-Based Offtakers	Hydrogen trading platforms, commodity traders (e.g., Trafigura, Vitol)	Act as intermediaries between producers and end-users, facilitating price discovery and liquidity in hydrogen markets.	Flexible contract structures with shorter durations. Hedging and risk management mechanisms often incorporated.	Lack of standardized hydrogen trading benchmarks. Credit risk of counterparties in emerging markets.

4.2.2. Barriers to Securing Long-Term Offtake Agreements

One of the primary challenges facing the hydrogen market is the reluctance of potential offtakers to commit to long-term purchase agreements. Unlike in more established energy markets, where standardized contracts such as Power Purchase Agreements (PPAs) provide revenue certainty, hydrogen offtake agreements remain highly customized, complex, and difficult to negotiate. The absence of reliable price discovery mechanisms, combined with the high cost of green hydrogen relative to fossil-based alternatives, creates significant risk for both buyers and sellers. Many industrial consumers are unwilling to sign long-term commitments without some form of price support, risk-sharing mechanism, or government-backed incentives that ensure cost parity with conventional fuels.

4.2.3. Financial Risks and Uncertainties for Investors and Producers

From an investment standpoint, the lack of secure long-term offtake agreements translates into significant project financing challenges. Hydrogen projects typically require high upfront capital investment, and without bankable offtake contracts, securing debt financing remains difficult. Lenders and investors need predictable revenue streams to assess a project's ability to generate stable returns. The volatility of energy input costs (e.g., electricity prices for electrolysis-based hydrogen production) adds further uncertainty, especially in markets where hydrogen price hedging mechanisms are underdeveloped. Additionally, the creditworthiness of offtakers plays a crucial role—industrial buyers may not always have investment-grade ratings, increasing counterparty risk and requiring additional credit support mechanisms such as parent company guarantees or letters of credit.

4.2.4. Policy and Regulatory Challenges in the EU

The policy and regulatory landscape for hydrogen in Europe remains highly dynamic, with ongoing updates to EU and national frameworks shaping market confidence. While initiatives such as the European Hydrogen Bank and H2Global aim to create demand-side certainty, challenges related to regulatory clarity, policy consistency, and infrastructure development continue to hinder large-scale offtake commitments. Addressing these barriers will require a coordinated approach among EU institutions, national governments, and private sector stakeholders to establish a cohesive hydrogen market that can support long-term investment and commercial viability.

Lack of Clarity on Regulatory Definitions of Green Hydrogen

The absence of a harmonized EU-wide definition of green hydrogen creates challenges for producers and offtakers alike. While the EU Renewable Energy Directive (RED II and III) provides a framework for defining Renewable Fuels of Non-Biological Origin (RFNBOs), uncertainty remains regarding additionality, temporal correlation, and geographic proximity rules for hydrogen produced from renewable electricity. This has led to delays in final investment decisions (FIDs) for hydrogen projects, as offtakers are unable to confirm whether their purchases will qualify for regulatory incentives and decarbonization targets.

For example, the French hydrogen strategy adopts a different approach to certification compared to Germany's H2Global initiative, where the German government procures green hydrogen under long-term contracts and resells it at a subsidized price to industrial buyers. The lack of consistency in defining hydrogen attributes complicates cross-border offtake agreements and limits the development of an integrated European hydrogen market.Impact of Mixed Messaging on Offtake Commitments

While the European Hydrogen Bank has been introduced to help reduce cost gaps between green hydrogen and fossil-based hydrogen, inconsistent policy signals from different EU institutions and national governments have created uncertainty for industrial offtakers. For example, while the EU aims to support domestic hydrogen production, several member states, such as Germany and the Netherlands, are prioritizing hydrogen imports from countries like Namibia, Chile, and Australia. This raises concerns among European producers regarding future demand certainty and price competition with imported hydrogen.

Furthermore, the EU's Fit-for-55 package and RePowerEU plan emphasize hydrogen's role in decarbonizing heavy industry and transport, but uncertainty around the implementation of the Carbon Border Adjustment Mechanism (CBAM) has left offtakers hesitant to sign long-term contracts. If CBAM carbon pricing adjustments are delayed or weakened, the economic case for green hydrogen in sectors like steel and chemicals may erode, further stalling offtake commitments.

Differences in National Regulatory Frameworks

EU member states have adopted divergent regulatory approaches to hydrogen, leading to market fragmentation. While Germany has established a comprehensive support scheme through H2Global, including subsidies and long-term offtake contracts, other countries such as Italy and Spain focus more on hydrogen blending in gas grids, creating varying offtake demand dynamics (the latter recently announcing offtaker led support mechanisms). Similarly, the UK has introduced its own Low Carbon Hydrogen Agreement (LCHA), which differs from EU frameworks, adding complexity for cross-border hydrogen projects involving both EU and UK-based buyers.

Moreover, differences in hydrogen storage and transportation regulations create further challenges. In France, the government is pushing for a hydrogen backbone infrastructure connected to industrial clusters, whereas in Poland and Eastern Europe, the focus is on retrofitting existing gas pipelines to accommodate hydrogen blending. These regional variations impact where and how offtakers can commit to long-term contracts, as the availability of storage and distribution infrastructure directly affects supply security and cost competitiveness.

4.2.5. Infrastructure and Supply Chain Bottlenecks

The successful execution of hydrogen offtake agreements is heavily dependent on the availability of adequate transportation, storage, and distribution infrastructure, as well as a stable supply chain for key equipment. However, these critical enablers remain underdeveloped across Europe, creating significant challenges for both hydrogen producers and potential offtakers.

A major constraint is the lack of dedicated hydrogen pipelines and storage facilities, which introduces supply security risks that deter offtakers from entering into long-term contracts. Unlike natural gas, which benefits from an extensive pipeline network, hydrogen infrastructure is still in its early stages, leading to concerns over delivery reliability and high transportation costs. Additionally, regulatory uncertainties regarding the blending of hydrogen into existing gas networks further complicate investment decisions. In regions such as Germany, the Netherlands, and the UK, pilot projects are exploring the feasibility of repurposing existing gas pipelines for hydrogen transport, but full-scale deployment remains years away. Without sufficient transport and storage capacity, offtakers may be forced to accept higher costs associated with alternative delivery methods, such as liquefied hydrogen (LH2), ammonia, or methanol-based transport, which further increases price uncertainty.

Beyond infrastructure limitations, supply chain bottlenecks in electrolyser production, storage equipment, and hydrogen refueling stations are slowing the pace of hydrogen project deployment. The demand for electrolysers, which are essential for green hydrogen production, is currently outpacing supply, leading to long lead times and cost escalations. European electrolyser manufacturers are struggling to scale production at the pace required to meet the ambitious targets of REPowerEU and national hydrogen strategies, adding another layer of uncertainty for project developers. These supply chain constraints create knock-on effects on project timelines, making it difficult for offtakers to commit to fixed delivery schedules and increasing the risk of contractual disputes over force majeure events caused by supply delays.

Additionally, the fragmented nature of hydrogen market development means that supply chain coordination remains weak. Hydrogen producers, infrastructure developers, and offtakers often operate independently, rather than as part of an integrated ecosystem. This lack of coordination leads to mismatches where hydrogen production capacity may come online before sufficient demand is secured, or vice versa. For example, industrial clusters in Spain and Portugal are developing large-scale green hydrogen production facilities but lack guaranteed long-term offtakers in key demand centers such as Germany and France due to insufficient cross-border pipeline infrastructure.

These supply chain and infrastructure limitations directly impact the structure of hydrogen offtake agreements. Given the heightened uncertainty, offtakers are more inclined to negotiate shorter contract durations or include volume flexibility clauses that allow them to adjust purchases in response to supply chain volatility. This, in turn, reduces bankability for project developers, making it harder to secure financing for large-scale hydrogen projects. To mitigate these risks, some offtake agreements now incorporate cost pass-through clauses, allowing producers to adjust contract pricing based on supply chain cost fluctuations, or risk-sharing provisions, where infrastructure delays trigger temporary contract modifications rather than full default penalties.

Until Europe accelerates hydrogen infrastructure deployment, storage solutions, and cross-border market integration, securing long-term, bankable offtake agreements will remain a challenge. Governments must prioritize the development of a hydrogen backbone, expand port infrastructure for ammonia and LH2 trade, and establish mechanisms to de-risk supply chain constraints through strategic investments. Without these structural enablers, offtakers will continue to hesitate in committing to long-term agreements, slowing the commercial rollout of green hydrogen across the European market.

4.3. The relationship between offtake and successful financing of Hydrogen projects

4.3.1. Bankability, cost and availability of capital

The Importance of Increasing Debt Financing in Green Hydrogen Projects

Maximizing the share of debt financing is crucial for improving the bankability and cost competitiveness of green hydrogen projects. Hydrogen production infrastructure requires significant upfront capital investment, and access to sufficient debt financing ensures that developers can execute projects without over-reliance on limited equity capital. Given the scarcity of equity capital available for large-scale hydrogen projects, an optimal capital structure that maximizes leverage is necessary to accelerate deployment and scale production.

Beyond equity availability, increasing the proportion of debt in a project’s capital structure directly reduces the weighted average cost of capital (WACC), improving overall project economics. Debt is not only cheaper than equity, but in most jurisdictions, interest expenses on debt are tax-deductible, further lowering the after-tax cost of capital. Additionally, as projects de-risk over time, developers can optimize financing through refinancing strategies, increasing leverage ratios and extending debt maturities to enhance capital efficiency.

Under the capital asset pricing model (CAPM), the cost of capital reflects the risk perception of a project compared to market risk benchmarks. By structuring robust risk allocation frameworks that assign specific risks to the parties best suited to manage them—such as offtakers, insurers, EPC contractors, and government entities—developers can lower the perceived project risk, making debt financing more attractive. Mechanisms such as sovereign guarantees, multilateral institution involvement (e.g., EIB, IFC), and structured project finance models can further enhance credit quality, ensuring long-term debt availability at competitive rates.

Ultimately, achieving a high leverage ratio through structured debt financing is essential for reducing the overall cost of capital, enabling greater financial sustainability for green hydrogen projects. As the industry matures and standardization improves, access to cheaper, longer-term debt financing will play a pivotal role in facilitating large-scale hydrogen investments and accelerating the energy transition.

Bankability challenges for hydrogen projects

The bankability of green hydrogen projects is a critical determinant of their ability to attract investment and secure long-term financing. Given the capital-intensive nature of hydrogen production infrastructure, lenders and investors require clear revenue certainty, risk mitigation mechanisms, and robust contractual frameworks to justify committing capital to these projects. Unlike traditional energy markets with well-established financing models, green hydrogen faces unique challenges due to its nascent demand base, evolving regulatory landscape, and technological uncertainties.

Offtaker credit

One of the primary factors influencing bankability is the creditworthiness of offtakers. Long-term purchase agreements with financially stable counterparties serve as a fundamental requirement for debt financing. Lenders typically assess the credit ratings, balance sheet strength, and payment security mechanisms of hydrogen buyers before extending loans to developers. However, many potential offtakers—particularly in emerging hydrogen applications such as mobility and industrial decarbonization—do not have the financial robustness to commit to bankable long-term offtake agreements without government-backed credit enhancements or risk-sharing mechanisms.

Project bankability

Project bankability is also influenced by the pricing structure of hydrogen offtake agreements. Contracts that incorporate fixed-price take-or-pay commitments provide greater revenue certainty, reducing lender concerns over demand volatility. Conversely, indexed pricing models that fluctuate based on energy markets, carbon credit values, or commodity benchmarks introduce revenue uncertainty, requiring additional hedging mechanisms to stabilize cash flows. Given the immaturity of hydrogen pricing benchmarks, many financiers prefer contracts that feature minimum price floors, price adjustment clauses, or government-backed Contracts for Difference (CfDs) to de-risk revenue exposure.

Risk Allocation

From a financial structuring perspective, lenders also consider the allocation of construction and operational risks in hydrogen projects. Green hydrogen production facilities require significant upfront capital expenditure (CAPEX) for electrolysers, renewable power integration, and storage infrastructure. Any delays in construction, supply chain disruptions, or cost overruns can threaten project viability, making engineering, procurement, and construction (EPC) contract structures and performance guarantees crucial for mitigating lender concerns. Additionally, long-term operational risks, such as fluctuating electricity prices affecting hydrogen production costs, must be addressed through power purchase agreements (PPAs) or cost pass-through clauses to ensure financial sustainability.

Risk mitigation

Credit risk mitigation mechanisms play an essential role in enhancing bankability. These may include parent company guarantees, letters of credit (LCs), political risk insurance, and multilateral development bank support to protect against offtaker default risks. In many emerging hydrogen markets, government-backed financing programs, such as Germany's H2Global mechanism or the EU's Hydrogen Bank, are being leveraged to provide credit support and facilitate long-term contract bankability.

4.3.2. How debt financiers assess bankability and price debt

Rating of hydrogen projects

When assessing the creditworthiness of debt issuance for an infrastructure project, rating agencies evaluate a range of factors, including project cash flow stability, counterparty credit strength, risk allocation frameworks, and debt repayment structures. They assess whether revenue models provide predictable income streams, whether contracts allocate risks effectively between stakeholders, and the degree to which financial covenants protect lenders. Key determinants include the presence of long-term offtake agreements, regulatory support mechanisms, and the ability to withstand downside scenarios such as cost overruns or demand fluctuations.

For green hydrogen projects, these considerations pose additional challenges. The nascent nature of hydrogen markets, lack of standardized pricing benchmarks, and evolving regulatory landscape introduce heightened uncertainty. As a result, hydrogen project bonds may require enhanced credit support, such as guarantees, government-backed subsidies, or multilayered debt structures to achieve an investment-grade rating. A strong contractual framework, including creditworthy offtakers and fixed-price agreements, will be essential in ensuring hydrogen project bonds attract institutional investors and reach viable financing terms.

Rating agencies assess risk and hence probability and default and hence expected loss and hence this can be used as a proxy for pricing of debt finance (by matching the rating to the prevailing bond yields). For example, Fitch Ratings has identified several key risk factors that influence the creditworthiness of green hydrogen projects in their rating methodology. These factors are crucial for investors and lenders when assessing the bankability of such projects. Some are unique to hydrogen, and some are common to infrastructure projects in general. The table below (from Fitch compares how hydrogen project risks compare to those of a thermal power project, a project type which is well known and has thousands to data points relating to default probabilities).

Table 4: Key Risk Factors in Green Hydrogen Projects

Risk Factor	Green Hydrogen	Thermal Power
Technological Maturity	Varying degrees of maturity, with some electrolyser technologies still at early commercialization stages.	Generally mature, though some emerging technologies exist in specific applications, like energy-from-waste.
Performance Metrics	Efficiency and availability vary depending on electrolyser type and renewable energy input.	Typically well-defined, with efficiency and availability metrics established over decades of operation.
Dispatchability	Theoretically dispatchable, but actual output depends on renewable energy availability, making it intermittent in some cases.	Fully dispatchable but frequently exposed to fuel supply and demand risks.
Asset Lifetimes	Electrolysers and other hydrogen infrastructure have relatively shorter lifespans compared to traditional thermal assets.	Generally long-lived assets but require significant maintenance and periodic overhauls.
Operational Costs	Less predictable due to fluctuations in electricity input costs and evolving maintenance requirements.	Generally stable and well-understood over asset lifetimes.
Storage of Output	Hydrogen storage is an integral component but remains costly and technically complex.	Typically, no storage is required for conventional thermal power plants.
Fuel Availability	Relies on availability of water and renewable electricity, with exposure to grid constraints and seasonal variations.	Relies on established fuel supply chains such as natural gas, coal, or biomass.
Revenue Model	Primarily tolling and availability-based contracts with increasing government-backed mechanisms such as Contracts for Difference (CfDs).	Revenue structures range from tolling-style and availability-based models to merchant market exposure.

Source: Fitch Ratings, "Green Hydrogen Project Finance Risks Same as or Higher than Thermal Power," May 18, 2023.

These risk factors underscore the importance of comprehensive due diligence and risk mitigation strategies in the development of green hydrogen projects. Stakeholders must carefully evaluate technological solutions, operational plans, market dynamics, regulatory environments, and financing structures to enhance project bankability.

Ultimately, the ability of green hydrogen projects to secure financing depends on their contractual certainty, risk allocation, and alignment with investor expectations. As the market matures, standardization of offtake agreements, regulatory clarity on hydrogen pricing mechanisms, and the expansion of government-backed risk mitigation tools will be essential in bridging the gap between developers and financiers. Addressing these challenges will unlock the necessary capital flows to scale green hydrogen production and integrate it into Europe's clean energy ecosystem.

The pricing and availability of debt at all revolves around the level of certainty of the cash flow aspects of a project and in the case of a default, the expected recovery amount, as the debt margin must cover (on average) the expected loss made through any defaults.

4.4. Hydrogen Contracting Models

4.4.1. Overview of Hydrogen Revenue Contracts

The hydrogen market is undergoing rapid expansion, with long-term revenue contracts serving as a cornerstone for securing financing for early low-carbon hydrogen projects. The structuring of these contracts plays a crucial role in mitigating financial risks, aligning operational models, and ensuring the bankability of projects. Drawing from established precedents in LNG and power purchase agreements (PPAs), hydrogen contracting models can be broadly classified into tolling agreements, sale-and-purchase agreements, and hybrid structures. Each of these models presents distinct risk allocation frameworks and commercial considerations that influence project financing and investor confidence.

Hydrogen contracting models play a pivotal role in ensuring long-term project viability, financial predictability, and risk alignment between producers and offtakers. While tolling agreements offer control over feedstock procurement, sale-and-purchase models provide greater revenue certainty for producers. As industry standards evolve, hybrid structures and government-backed revenue stabilization mechanisms like CfDs are emerging as key enablers of a scalable, investable hydrogen economy. The selection of the appropriate contracting model is fundamental to a project's success, influencing not only its financial viability but also its ability to attract capital and secure long-term regulatory and policy support.

Understanding how these models fit within the broader financial and commercial framework of hydrogen projects is crucial. The selection of a contracting model directly impacts a project's ability to secure financing, manage risk, and align with regulatory and policy frameworks. Lenders and investors assess these models based on their revenue stability, risk-sharing mechanisms, and overall viability within evolving hydrogen markets.

4.4.2. Tolling Agreements vs. Sale-and-Purchase Models

Tolling Agreements

Under a tolling model, the hydrogen production facility acts as a service provider rather than a seller of hydrogen. The offtaker procures input feedstocks—such as renewable electricity and water in the case of green hydrogen or natural gas for blue hydrogen—and pays a processing fee to the hydrogen producer. This structure closely mirrors LNG tolling agreements, in which a liquefaction plant processes customer-owned natural gas into LNG for a fee.

- Risk Allocation: The offtaker assumes commodity price risk associated with feedstock procurement, while the producer retains operational and technical risks related to hydrogen production.
- Advantages: This model benefits financially robust offtakers that seek to retain control over energy procurement strategies and minimize exposure to fluctuating processing costs.
- Challenges: Hydrogen producers relying on tolling fees may encounter challenges in securing debt financing unless the offtaker possesses strong creditworthiness or offers adequate credit support instruments.

4.4.3. Sale-and-Purchase Agreements (SPAs)

In a sale-and-purchase model, the hydrogen producer procures raw materials, processes them into hydrogen, and sells the output to an offtaker at a predetermined price structure. This approach resembles traditional commodity trading frameworks, where the producer assumes both upstream and processing risks before selling a finished product.

- Risk Allocation: The producer assumes both feedstock and operational risks, while the offtaker agrees to a purchase obligation under specified terms.
- Advantages: This model facilitates greater revenue predictability, making it attractive for lenders and institutional investors seeking stable cash flows.
- Challenges: Producers must hedge against input cost volatility and establish reliable feedstock procurement strategies to ensure economic feasibility.

4.4.4. Hybrid Structures

Hybrid models integrate elements of both tolling and sale-and-purchase agreements to balance risk allocation between producers and offtakers. For instance, some agreements allow offtakers to supply electricity while leaving water procurement to the producer. In other cases, joint ventures between hydrogen producers and industrial users distribute both capital investment and operational risks, fostering greater alignment between supply and demand.

In the evolving hydrogen market, hybrid structures are increasingly being utilized to overcome the financing challenges of pure tolling or sale-and-purchase models. These structures can provide enhanced flexibility by allowing project stakeholders to optimize operational efficiencies while ensuring long-term revenue security. Governments and financial institutions often support hybrid models through risk-mitigation mechanisms such as guaranteed minimum price structures, volume guarantees, and policy-driven incentives.

4.5. Key Contractual Considerations (the theory)

4.5.1. Contract Quantities and Volume Flexibility

Market demand for green hydrogen remains uncertain, and project developers rely on long-term offtake commitments to secure financing. If an offtaker fails to take the contracted volume, the seller may face stranded production and revenue shortfalls. These provisions exist to ensure revenue stability and usually take the form of specifying who takes volume risk (take and pay vs take or pay, the latter being the norm in debt financed PPAs in the electricity industry):

- Take-or-pay: The offtaker commits to paying for a fixed quantity of hydrogen, irrespective of actual consumption. Some agreements incorporate make-up provisions, allowing deferred purchases in future periods.
- Take-and-pay: The offtaker must both take physical delivery and pay for the agreed volume; failure to do so results in contractually defined penalties.
- Minimum Term Requirements: Hydrogen project financings require contract tenors of at least 15–20 years to align with debt repayment schedules, as seen in offshore wind and LNG contracts.
- Government Policy Dependency: The demand for hydrogen is often shaped by government mandates (e.g., hydrogen blending targets, industrial decarbonization incentives). Lenders are generally unwilling to take exposure to policy-driven demand risk, meaning buyers must bear this uncertainty.
- Flexibility mechanisms: Volume flexibility provisions allow adjustments based on renewable energy variability or fluctuations in industrial demand, particularly in co-located green hydrogen projects integrated with intermittent renewable energy sources.

The structuring of these contractual obligations directly impacts project bankability. Take-or-pay structures, for example, provide lenders with assured revenue streams, reducing financial risk exposure. However, in nascent hydrogen markets with uncertain production profiles or uncertain use case volumes, offtakers may resist long-term fixed obligations, necessitating alternative mechanisms such as volume-adjustable agreements or indexed commitments.

4.5.2. Pricing Mechanisms

Given the absence of a mature hydrogen spot market, pricing structures should be tailored to mitigate exposure to cost volatility and evolving market dynamics:

- Fixed price agreements: Offer revenue certainty but expose offtakers to potential market price disparities over time.
- Indexed pricing: Links hydrogen prices to reference benchmarks such as natural gas, ammonia, or electricity indices to provide pricing transparency.
- Contracts for Difference (CfDs): Frequently deployed in government-backed initiatives, CfDs stabilize revenue by compensating for deviations from a predefined strike price.
- Price review clauses: Many agreements incorporate periodic renegotiation triggers to accommodate evolving market conditions, ensuring pricing mechanisms remain viable over the contract term.

Aurora provides a useful exposition of the relationship between the cost of power and hydrogen pricing level and variability. The diagram illustrates the three primary pricing structures used in Hydrogen Purchase Agreements (HPAs): Indexed Pricing Model, Tolling Model, and Fixed Pricing Model. These models define how hydrogen prices are determined based on the cost of power and the risk allocation between developers and offtakers. The diagram highlights the trade-offs between price stability and cost flexibility in structuring hydrogen offtake agreements, which are critical in designing bankable contracts for hydrogen projects.

1. Indexed Pricing Model

- Cost of Power: Developers pay the cost of power, and these costs are embedded in the HPA.
- Hydrogen Prices: The price of hydrogen is variable and fluctuates according to the cost of power, meaning that hydrogen prices follow market electricity prices. This structure exposes offtakers to price volatility but can be beneficial when power costs are low.

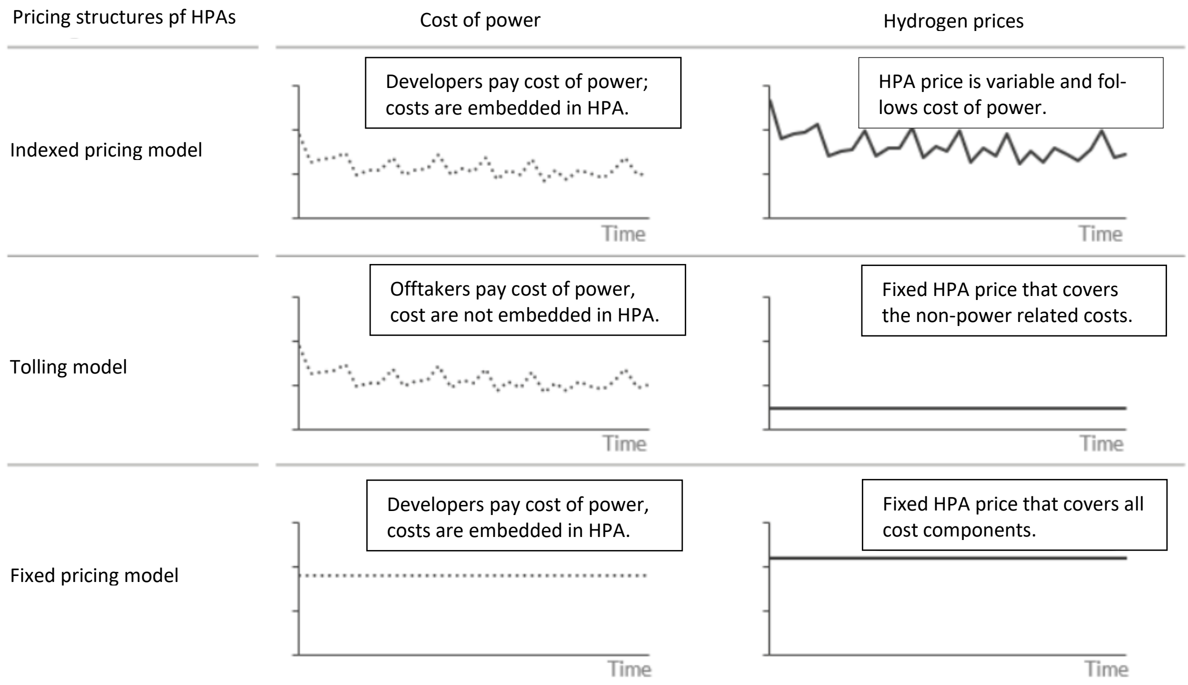
2. Tolling Model

- Cost of Power: Here, the offtaker, rather than the developer, bears the cost of power. As a result, power costs are not embedded in the HPA.
- Hydrogen Prices: The hydrogen price remains fixed and only includes non-power-related costs, such as operational and capital costs. This model is commonly used in industries where the offtaker has direct access to energy markets and prefers to manage electricity procurement independently.

3. Fixed Pricing Model

- Cost of Power: The developer assumes the cost of power, incorporating it into the HPA.
- Hydrogen Prices: The price of hydrogen is fixed and covers all cost components, including energy procurement, operational costs, and capital expenses. It provides certainty and price stability to both parties but may include a premium to account for future energy price fluctuations.

Figure 2: How pricing models address power procurement risk



Source: Aurora 2024

Implications for Market Participants

1. Investors & Lenders: Fixed pricing models are more bankable as they provide predictable cash flows. Indexed pricing models carry higher risks but can be attractive in markets with stable or declining electricity costs.
2. Offtakers: Tolling models may be preferred by energy-intensive industrial users with direct access to power markets, while fixed pricing models offer stability but may come at a higher cost.
3. Policy & Regulation: Indexed models may align with Contracts for Difference (CfDs) and government subsidy mechanisms, while fixed pricing contracts may require additional guarantees to attract financing.

In hydrogen project financing, pricing mechanisms must provide both investor confidence and market adaptability. Indexed pricing, for instance, aligns hydrogen costs with broader energy market fluctuations, making it more palatable for offtakers hesitant to commit to fixed-price contracts. However, without an established benchmark market, pricing structures must be designed with robust adjustment and dispute resolution mechanisms.

4.5.3. Creditworthiness and Risk Mitigation

The creditworthiness of the offtaker is critical to probability of default and hence bankability and pricing – an offtaker may be unable to meet its financial obligations over the contract term, leading to payment default and undermining the project's bankability:

- Investment Grade Creditworthiness Requirements: Lenders typically require the offtaker to hold an investment-grade rating (BBB-/Baa3 or higher). If the buyer does not meet this threshold, it may need to provide a creditworthy guarantor or furnish letters of credit (LoCs) as financial security.
- Covenants to Maintain Credit Rating: In cases where an offtaker's financial health is critical to the project's stability, lenders may impose financial covenants that require the buyer to maintain a certain credit rating or restrict leverage.
- Step-in Rights for Lenders: If an offtaker defaults, financing institutions may step in to preserve the contract and ensure continued cash flow to the project.
- Government-backed guarantees or risk-sharing mechanisms to enhance credit profiles and facilitate project financing.

As hydrogen markets develop, financial institutions and multilateral organizations play a growing role in providing credit enhancement mechanisms to de-risk early projects. Structured financial instruments such as blended finance models and sovereign-backed guarantees are increasingly used to offset offtaker credit risks.

4.5.4. Force Majeure and Change-in-Law Provisions

Hydrogen projects are also susceptible to disruptions arising from regulatory shifts, supply chain constraints, and energy market fluctuations. Force majeure clauses addressing unforeseen disruptions, including extreme weather events and geopolitical risks Contract usually incorporate.

- Change-in-law protections, ensuring regulatory modifications impacting production economics are equitably allocated between parties.
- Back-to-back risk alignment, particularly for projects reliant on power purchase agreements (PPAs) for renewable electricity procurement.

Ensuring that force majeure and regulatory risk clauses align with project lender expectations is essential in safeguarding long-term financial stability. Developers must also evaluate contractual backstops, termination rights, and policy-driven risk-sharing frameworks to protect against adverse regulatory developments. Long stop force majeure provisions are often heavily negotiated and are examined in detail by financiers.

4.6. Observed recent Market Practices from contracted deals (the practice)

The hydrogen offtake market is currently dominated by conservative, fixed-price agreements, with key contractual terms aligning with those seen in long-term commodity contracts. These structures ensure financial stability for producers, but offtakers are seeking increased flexibility in pricing and volume commitments.

As the hydrogen economy evolves, contractual structures will likely transition toward greater flexibility, incorporating shorter durations, price adjustments, and volume variability mechanisms. However, in the immediate term, long-term fixed-price agreements remain critical for bankability, securing financing, and establishing market confidence.

Hydrogen offtake agreements are predominantly structured as long-term fixed-price contracts with a single major offtaker. Notable examples include projects such as Puertollano and CEOG, where long-term commitments underpin project financing. Offtaker participation as a co-sponsor is still rare, but cases such as the Swedish H2 Green Steel project indicate a growing trend toward strategic equity participation from industrial buyers (Proximo 2024).

Market practice has shown that fixed-price agreements are typically structured with a multi-decade term, often segmented into distinct periods such as an initial production phase followed by a structured delivery phase. These agreements generally include take-or-pay provisions, requiring the offtaker to purchase contracted volumes or compensate the seller for undelivered quantities. Delivery scheduling is often flexible within predefined quantity bands, allowing for minor volume adjustments to accommodate operational variances.

While long-term commitments remain dominant, developers report increasing interest in short-term procurement models. However, securing project finance requires stable revenue streams, making it challenging to structure shorter-duration agreements in the current market.

4.6.1. Pricing Structures in Offtake Agreements

Pricing in hydrogen contracts is generally fixed, based on a cost-plus model where the offtake price covers fixed and variable costs plus a margin. Market practice has demonstrated that financial models often assume segmented pricing, where an initial fixed rate includes capital recovery and operational costs, followed by indexation mechanisms after a defined period. This ensures that operational costs remain aligned with inflation and evolving cost structures over time.

Developers have explored alternative pricing structures, but variable pricing remains uncommon. Two viable models include:

1. Index-linked pricing: Hydrogen prices tied to fossil fuel or electricity indices, often incorporating floors and caps to provide stability.
2. Pre-agreed declining price trajectory: A structured reduction in price over time, reflecting anticipated cost improvements in hydrogen production.

Market feedback indicates that offtakers favor a hybrid pricing model, often securing 25–50% of contracted volumes at fixed prices, with the remainder linked to energy price indices (e.g., natural gas benchmarks).

4.6.2. Volume Commitments and Contract Flexibility

Hydrogen offtake agreements typically enforce fixed volume commitments with take-or-pay provisions. Market agreements have demonstrated that sellers generally retain control over production scheduling, with offtakers committing to a predefined minimum and maximum volume range per delivery cycle. In certain cases, operational tolerances allow for minor deviations (e.g., ±2%), ensuring production and logistical flexibility.

Common contractual features include:

- Operational Tolerances: Contracts may permit a 2% flexibility range in delivered volumes, ensuring operational leeway.
- Seller Shortfall Liability: If the seller fails to deliver the agreed volume, the buyer is entitled to reimbursement for replacement costs, subject to predefined caps.
- Buyer Shortfall Provisions: If the buyer fails to take contracted volumes, they must pay the seller for undelivered quantities, subject to resale provisions.

Despite rigid volume requirements, some flexibility mechanisms exist. Certain agreements allow for 5–10% volume deviations, but fully variable volume contracts remain absent from the market. However, offtakers express a preference for contracts that blend fixed and flexible volume commitments, with floors and caps on purchases.

4.6.3. Risk Allocation and Credit Protections

Most agreements the authors have observed have incorporated structured credit risk mitigation, including:

- Investment Grade Creditworthiness Requirements: If the buyer's credit rating falls below investment-grade thresholds, they must secure credit enhancement instruments, such as letters of credit covering a significant portion of annual expected production.
- Step-in Rights for Lenders: Contracts often feature provisions allowing lenders to step in before termination, ensuring financial continuity.
- Force Majeure Provisions: In cases of extreme disruption, force majeure clauses provide termination rights after predefined extended periods, ensuring that long-term contracts remain resilient to unforeseen circumstances.

Such provisions ensure that long-term contracts remain bankable, mitigating counterparty risk and protecting lenders.

4.6.4. Market Evolution: Moving Towards Greater Flexibility

Currently, hydrogen offtake structures remain producer-friendly, prioritizing fixed volumes, fixed pricing, and long-term commitments to ensure financial viability and investor confidence, but also in some cases because the offtaker is a shareholder in the producer. However, the market is slowly shifting toward more flexible structures, including:

- Shorter contracts (<10 years) to align with corporate decarbonization targets.
- Renegotiation clauses tied to significant regulatory or market shifts.
- Alternative offtake models, such as tolling agreements, where the buyer provides input materials and pays a processing fee.

- More sophisticated volume flexibility, particularly as hydrogen storage and transportation infrastructure improve.

Offtakers increasingly emphasize contract adaptability, recognizing that rigid agreements may hinder market growth. However, in the near term, fixed-price, take-or-pay agreements remain the market standard until hydrogen trading markets mature and alternative pricing mechanisms gain broader acceptance.

5. Current Financial Support Mechanisms in Europe and the US

5.1. Current Financial Support Mechanisms in Europe and the US

European Union Interventions in the Hydrogen Market

The European Union has taken a structured and phased approach to developing its hydrogen economy, integrating policy, regulatory frameworks, and financial support mechanisms to stimulate investment and deployment. This timeline outlines key milestones in the evolution of EU hydrogen policy, from the initial EU Hydrogen Strategy in 2020 to the latest advancements in market regulation, infrastructure development, and funding initiatives.

The timeline reflects the EU's commitment to scaling up renewable and low-carbon hydrogen production while fostering an integrated hydrogen market across sectors such as industry, transport, and power generation. The introduction of RePowerEU targets significantly accelerated ambitions, setting the stage for mass adoption, infrastructure planning, and financial interventions like the European Hydrogen Bank. Regulatory measures such as the Renewable Energy Directive (RED III), FuelEU Maritime, and RefuelEU Aviation reinforce hydrogen's role in decarbonization by setting legally binding targets.

Despite strong policy backing, investment bottlenecks remain, with 90% of announced EU hydrogen projects still awaiting a Final Investment Decision (FID). The EU-wide pilot auction under the Hydrogen Bank has been an early attempt at bridging the cost gap between renewable hydrogen and fossil alternatives, but ongoing initiatives—including the Decarbonized Gas and Hydrogen Package—are critical in defining the long-term regulatory landscape. The development of a hydrogen pipeline network and cross-border logistics infrastructure will be equally essential for scaling production and market integration.

The following table provides a detailed chronology of major policy interventions, regulatory updates, and investment mechanisms shaping the European hydrogen sector.

Table 5: EU Hydrogen Support Policy timeline

Date	Event/Milestone	Description/Key Details

08 July 2020	EU Hydrogen Strategy	Initial strategy outlined a vision for clean hydrogen development and deployment, with the idea of 6 GW of renewable hydrogen electrolysers, the replacement of hydrogen production and the regulation for liquid hydrogen markets.
18 May 2022	RePowerEU Aspirational Targets	Set ambitious targets of 10 million tons of domestic and 10 million tons of imported renewable hydrogen by 2030 to reduce reliance on Russian fossil fuels, with planning of hydrogen infrastructure.
16 March 2023	SWD Defining Activities of the Hydrogen Bank	A Staff Working Document detailed the activities and mechanisms of the European Hydrogen Bank.
01 June 2023	Delegated Acts Defining Rules for RFNBOs	Specifies rules and criteria for Renewable Fuels of Non-Biological Origin (RFNBOs), which are essential for ensuring the sustainability and renewability of hydrogen production, to include new applications in steel and transport, and hydrogen for electricity balancing purposes.
09 October 2023	RefuelEU Aviation Adopted	Mandates a rising share of Sustainable Aviation Fuels (SAF), including synthetic aviation fuels or RFNBOs, from 1.2% in 2030 to 35% in 2050.
12 September 2023	FuelEU Maritime Adopted	Sets targets for reducing the greenhouse gas intensity of fuels used in the maritime sector. Includes incentives for RFNBOs with high decarbonization potential. If the RFNBO share is less than 1% by end of 2031, a subtarget will apply from 2034.
20 November 2023	Renewable Energy Directive (RED III) Enters into Force	Sets binding targets for renewable energy deployment across various sectors, including industry and transport, with specific sub-targets for RFNBOs.
28 November 2023	First Projects of Common Interest (PCI) in Hydrogen Announced	Announces the first wave of hydrogen projects recognized as Projects of Common Interest (PCIs), facilitating faster permitting and access to funding for key infrastructure projects, for the creation of "Hydrogen Valleys" and cross-border logistical infrastructure.
November 2023 - February 2024	First EU-Wide Pilot Auction	High participation with 132 bids from 17 EU countries. Seven bids were selected for support for EUR 720 million, with a clearing price of EUR 0.48 / kg of H2 for 1.5 GWe of electrolyser capacity and the upscale to all hard-to-decarbonise sectors.

21 May 2024	Adoption of Decarbonized Gas and Hydrogen Package	Establishes rules for the future hydrogen network, defines low-carbon gases (including hydrogen), and creates a regulatory framework conducive to hydrogen market development, and the expansion of hydrogen-derived synthetic fuels.
	Adoption of Delegated Acts	The Commission to adopt delegated acts specifying the methodology for assessing greenhouse gas emissions savings from low-carbon fuels through an EU-wide infrastructure network and an open international market with € as benchmark.
Until Dec 31, 2029	Market Development Mechanism is Active	The voluntary mechanism under the European Hydrogen Bank with a wide scope and the possibility to contract a service provider, provide liquidity support by Member States, and set up a coordination group.
Ongoing	Project Pipeline Development & Investment Decisions	Europe is leading in terms of hydrogen project announcements. Key challenge is finalizing investments, as currently 90% of hydrogen projects in the EU are awaiting a Final Investment Decision.

The key support mechanisms, include the Innovation Fund, Important Projects of Common European Interest (IPCEIs), and the European Hydrogen Bank (EHB). Key EU Support Mechanisms. The table below sets out these initiatives in more detail.

Table 6: Summary of Initiatives

Initiative	Category	Description
Innovation Fund	**Funding Scale and Eligibility**	The Innovation Fund supports both large-scale and small-scale projects, allowing blending with other EU funding sources.
	Large-Scale Projects	Projects requiring **>€7.5 million CAPEX** follow a **two-stage application process**, starting with an **Expression of Interest (EoI)** and culminating in a **full proposal**.
	Small-Scale Projects	Projects with **<€7.5 million CAPEX** benefit from a **streamlined, single-stage application process**, reducing administrative burdens.
	Blending with Other EU Funds	Permitted with **InvestEU, European Structural Funds, and Connecting Europe Facility (CEF)**, provided it complies with EU **double funding** rules.
IPCEI	**Important Projects of Common European Interest (IPCEIs)**	Facilitates **state aid for large cross-border hydrogen projects** addressing market failures and strategic EU objectives.

	IPCEI Structure	Involves **multi-member state collaboration** and **private-sector partnerships**, focusing on **hydrogen production, infrastructure, and end-use applications**.
	Approved Hydrogen IPCEIs	The **European Commission has approved two waves of IPCEIs**, with additional initiatives under development.
European Hydrogen Bank	**European Hydrogen Bank (EHB)**	Aims to **stimulate private investment** in hydrogen projects and **bridge cost differentials** between renewable and fossil-based hydrogen.
	EHB Auction Mechanism and Structure	The **pay-as-bid auction system** determines subsidies per kilogram of renewable hydrogen produced.
	Fixed Premium Payments	Successful bidders receive subsidies over a **ten-year period**, contingent upon verified hydrogen production.
	Buyer-Contract Alignment	Bidders must demonstrate **preliminary agreements with hydrogen buyers**, ensuring **demand certainty**.
	Auction Ceiling Prices	The first auction set a **ceiling price of €4.50/kg**, with **winning bids averaging €0.40/kg**, indicating strong market participation.
	Market Impact	EHB funding mechanisms **encourage competition**, drive **cost reductions**, and improve **market liquidity**

Lessons from the First Wave of Hydrogen Auctions

The first wave of hydrogen auctions has provided valuable lessons for refining future auction designs. These include the need to:

- Streamline the application process to reduce administrative burdens on bidders.
- Provide clear and consistent guidance on eligibility criteria and evaluation procedures.
- Incorporate feedback from stakeholders to improve the auction design.

Auctions help address investment uncertainties by providing producers with revenue certainty and reducing the risk associated with long-term investments in hydrogen production facilities and seek to ensure cost competitiveness with fossil-based hydrogen. These challenges include:

- High capital costs for electrolyser equipment.
- High electricity costs.
- Limited access to financing.

5.1.1. Pricing Mechanisms and Premium Considerations

The European Hydrogen Bank employs a fixed premium pricing mechanism, which provides producers with a guaranteed price for their hydrogen. This premium is designed to compensate producers for the additional costs associated with producing renewable hydrogen. The price of green hydrogen remains higher than that of fossil-based hydrogen, largely due to the higher costs of renewable energy and electrolyser equipment. However, as technology advances and the cost of renewable energy declines, the price gap between green and fossil-based hydrogen is expected to narrow. The outcomes of EU hydrogen auctions have a significant impact on market perception. Successful auctions demonstrate the viability of renewable hydrogen and attract additional investment in the sector.

Critique by market participants on European Interventions

While the EU has implemented various funding mechanisms to support the development of green hydrogen, including the European Hydrogen Bank and Innovation Fund, these interventions face several shortcomings that hinder their effectiveness in fostering a robust hydrogen market.

One major weakness is the heavy reliance on competitive auctions. While auctions can drive down the cost of hydrogen production, they often prioritize short-term price reductions over long-term project viability. This can create a "race to the bottom," potentially compromising project quality, technological innovation, and supply chain resilience. Market participants have expressed concerns that the intense price competition in auctions may deter smaller players and favor larger, more established companies with greater financial resources. Moreover, the auction-based approach may not adequately address the specific needs of different sectors or regions, leading to suboptimal allocation of resources and a slower pace of decarbonization in some areas.

Another challenge is the lack of sufficient revenue certainty for developers. Many projects struggle to secure long-term offtake agreements, which are essential for obtaining financing and ensuring project bankability. The current funding mechanisms often fail to adequately address this issue, leaving developers exposed to market risks and price volatility. This uncertainty can discourage investment and slow the deployment of green hydrogen infrastructure. The EU needs to shift towards instruments that will create revenue certainty, and which will encourage the uptake of hydrogen, not only the generation.

Furthermore, the complexity and bureaucratic nature of EU funding application processes can be a significant barrier for project developers. The application procedures are often perceived as cumbersome, time-consuming, and requiring specialized expertise. This can deter smaller companies and startups from participating, limiting innovation and competition. The lack of transparency in the decision-making process also raises concerns about fairness and equity.

Market commentators have also criticized the EU's approach for its lack of coordination and strategic vision. The various funding mechanisms are often implemented in a fragmented manner, without a clear overarching strategy for developing a cohesive hydrogen ecosystem.

This can lead to duplication of efforts, inefficiencies, and a lack of synergy between different initiatives. A more integrated and coordinated approach is needed to ensure that EU funding effectively supports the development of a sustainable and competitive hydrogen market. There is a need for a strong overarching strategy.

While the EU has made significant progress in promoting green hydrogen, its current funding mechanisms require further refinement and improvement. A more balanced and strategic approach is needed to address the challenges of revenue certainty, project bankability, and market coordination. By learning from the experiences of other countries and engaging in open dialogue with market participants, the EU can create a more effective and sustainable framework for supporting the growth of the green hydrogen sector. The EU also needs to be more in line with member states to encourage uptake and offer a streamlined service.

5.1.2. United States: US H2Hubs Demand-Side Support Mechanism

The U.S. Department of Energy's (DOE) Regional Clean Hydrogen Hubs (H2Hubs) Program seeks to mitigate this risk by directly addressing the lack of secured long-term buyers, which is crucial for project bankability. The DOE's demand-side support mechanisms aim to bridge the gap between supply and demand, ensuring that early-stage hydrogen projects reach final investment decisions (FIDs) and scale into fully commercial operations.

5.2. How the U.S. H2Hubs Initiative Addresses Offtake Risk

5.2.1. Demand-Side Support to Counteract Offtake Hesitancy

The DOE is investing up to $1 billion to create a demand-side support mechanism, which directly incentivizes long-term offtake commitments. The hydrogen market faces a chicken-and-egg problem: potential hydrogen consumers hesitate to enter long-term contracts until stable supply is available, while hydrogen producers cannot secure financing without binding offtake agreements:

- Contracts for Difference (CfDs): The DOE is expected to act as the counterparty in a CfD structure, covering the gap between a hydrogen producer's cost and an agreed-upon price with an offtaker. This is similar to EU hydrogen auction mechanisms, but with a regional focus tailored to specific hub demand.
- Fixed Support Payments: Direct subsidies to industrial hydrogen users reduce the cost burden of switching to clean hydrogen.
- Market-Maker Mechanism: The DOE may act as an intermediary buyer to aggregate demand and resell hydrogen, de-risking investments in new infrastructure.
- By guaranteeing a level of demand, these measures encourage offtake agreements and improve the financing conditions for hydrogen projects, particularly those backed by project finance structures reliant on long-term revenue certainty.

5.2.2. Public-Private Partnerships and Buyer Credit Risk Mitigation

Hydrogen hubs in the U.S. are structured as public-private partnerships (PPPs), helping attract private capital while ensuring federal and state cost-sharing. This model reduces buyer credit risk in two keyways:

1. Direct public-sector funding helps secure initial demand, allowing first-mover industrial users to adopt hydrogen with lower financial exposure.
2. Long-term government-backed CfDs improve price stability, reducing uncertainty for private offtakers and lowering the cost of capital for hydrogen producers.

5.2.3. Comparison to EU Offtake Challenges

Both the U.S. and EU face similar offtake challenges, but the nature and scale of interventions differ in key areas.

Table 7:US vs EU interventions

Offtake Challenge	U.S. Hydrogen Hubs Approach	EU Hydrogen Bank Approach	Qualitative & Quantitative Differences
Demand Uncertainty	$1B in demand-side incentives to encourage offtake commitments.	€1.2B in auction-based price support, using CfDs.	EU approach is more auction-driven, whereas U.S. uses regional market creation.
Buyer Credit Risk	DOE may act as a market-maker or CfD counterparty, ensuring stable revenue streams.	No direct government offtake, but CfD mechanisms de-risk pricing.	U.S. model provides greater direct intervention, reducing investor risk.
Industrial Adoption	Targeted industrial hubs to co-locate supply & demand for regional benefits.	Pan-European approach, incentivizing cross-border projects.	EU model promotes broader trading, while U.S. focuses on regional synergies.
Pricing Mechanism	Hybrid model: CfDs, fixed support, feasibility grants.	Pay-as-bid auctions, setting a premium per kg of hydrogen.	U.S. directly funds feasibility studies, whereas EU relies on competitive bidding.
Regulatory Certainty	IRA tax credits ($3/kg) complement DOE incentives, but 45V eligibility rules remain uncertain.	EU regulations fragmented across member states, slowing market adoption.	U.S. offers stronger tax incentives, while EU faces cross-border policy challenges.

Key Takeaways

1. U.S. approach is more interventionist: The DOE directly funds demand-side support, while the EU uses market-driven auctions to determine subsidy levels.

2. EU faces regulatory fragmentation, whereas the U.S. has a clearer federal framework, even if IRA tax credit rules are still under debate.
3. The U.S. Hydrogen Hubs strategy focuses on regional demand aggregation, helping industrial clusters transition to hydrogen, whereas the EU model encourages international trade and pan-European investment.
4. Both regions see hydrogen offtake as a major risk, but the U.S. may achieve quicker adoption through direct market intervention, while the EU approach relies on competitive market maturation over time.

The United States has pursued a direct interventionist strategy through the Department of Energy's Hydrogen Hubs (H2Hubs) initiative. The H2Hubs are designed to accelerate the development of regional hydrogen ecosystems by fostering collaboration between producers, consumers, and infrastructure developers. While the H2Hubs aim to stimulate demand and facilitate offtake by aggregating potential users and providing funding for infrastructure development, they do not directly guarantee offtake agreements. Rather, they provide a framework and financial incentives to encourage the formation of these agreements. The actual offtake contracts are still subject to negotiation between the relevant parties and depend on market conditions, project economics, and specific contractual terms. The H2Hubs serve as a catalyst for offtake, reducing risks and connecting stakeholders, but the ultimate realization of these agreements depends on successful commercial negotiations within the established framework.

5.3. United Kingdom

To incentivize electrolyser deployment, the UK government has established a multi-faceted approach encompassing both direct capital grants and revenue support mechanisms. The Net Zero Hydrogen Fund (NZHF), for example, provides direct financial assistance to cover the upfront capital costs of constructing low-carbon hydrogen production facilities. RWE's Pembroke Phase 2 scheme is one of the seven selected for funding to supply the UK with cleaner fuel. Furthermore, the Hydrogen Production Business Model (HPBM) offers revenue certainty through 15-year contracts based on a 'contract for difference' mechanism, de-risking investments in electrolysers by guaranteeing a strike price for produced hydrogen

5.3.1. Electrolyser Funding and Capital Grants

The UK government recognizes that electrolyser technology is crucial for producing low-carbon hydrogen from renewable energy sources. To encourage the deployment of electrolysers, several funding mechanisms are available, providing both capital grants and operational support.

Hydrogen Production Business Model (HPBM) / Hydrogen Production Contracts (HPCs):

This business model provides revenue support for hydrogen production projects through long-term contracts, effectively de-risking investments in electrolyser facilities. Producers compete for contracts in allocation rounds. Successful projects are granted a contract for a set term (e.g., 15 years).

Under an HPBM, hydrogen producers receive a "strike price" (a guaranteed price for their hydrogen) for the duration of the contract. If the reference price (market price of hydrogen) falls below the strike price, the producer receives a top-up payment from a government-managed entity to cover the difference. Conversely, if the reference price exceeds the strike price, the producer pays back the excess revenue to the government. By guaranteeing a certain revenue stream, the HPBM reduces the risk associated with large capital investments in hydrogen production facilities.

Allocation Rounds: Projects compete for HPCs in regular allocation rounds (HARs). The allocation process considers factors such as the project's cost-effectiveness, emissions reductions, and contribution to wider policy objectives.

Net Zero Hydrogen Fund (NZHF):

A capital grant scheme providing direct financial support for the capital costs of constructing low-carbon hydrogen production facilities, including electrolysers. It helps bridge the "green premium," making low-carbon hydrogen competitive with conventional fossil-based hydrogen.

Project developers apply for grants through competitive funding rounds. The NZHF assesses applications based on criteria such as technology readiness, project viability, emissions reductions, and value for money. Successful projects receive grants to cover a portion of their capital expenditures. It reduces the financial burden associated with building hydrogen production facilities, incentivizing companies to invest in this sector.

Advanced Manufacturing and Infrastructure Stream (AMIS):

The AMIS provides financial assistance in the form of capital expenditure to projects to invest in the technologies and infrastructure needed for large-scale production of components, machinery, and equipment for net zero sectors, including hydrogen. Businesses can bid for financial assistance from the AMIS, which grants funds to eligible projects through competitive funding rounds.

It provides financial incentive to invest in manufacturing capabilities in order to support domestic supply chain expansion. These funding mechanisms aim to overcome the high upfront capital costs associated with electrolyser deployment, which remains a key barrier to widespread adoption.

Interaction with Contracts for Difference (CfDs)

The UK's broader energy strategy utilizes Contracts for Difference (CfDs) to support renewable electricity generation. They interact in a couple of ways:

1. Electrolysers and Renewable Electricity: Electrolysers producing hydrogen ideally use renewable electricity. The UK’s CfD scheme supports the development of renewable energy projects. These projects can supply electrolysers that generate hydrogen, with the end goal of producing low-carbon hydrogen, meaning the

interaction between CfDs and Hydrogen schemes can minimize the carbon footprint of hydrogen production and ensure adherence to low-carbon standards.

2. HPBM & De-risking investment: HPBMs are a type of CFDs and can offer a guaranteed price, with the intention to de-risk investment. These mechanisms provide the investor with certainty and stability for investors, promoting long-term investment.

5.3.2. Key Takeaways: UK vs. EU Hydrogen Incentives

1. UK favours direct revenue support, while the EU prioritizes broader market integration: The UK's Hydrogen Production Business Model (HPBM) uses a Contracts for Difference (CfD) style mechanism to provide revenue certainty for producers, while the EU relies on subsidy schemes such as the European Hydrogen Bank and Innovation Fund to stimulate hydrogen production and demand.
2. Regulatory agility in the UK vs. EU complexity: The UK's centralized policymaking allows for faster implementation of hydrogen incentives, whereas the EU faces regulatory fragmentation across 27 member states, requiring harmonization efforts that can slow policy adoption.
3. UK support focuses on domestic hydrogen production, while the EU emphasizes international trade: The UK's model aims to develop low-carbon hydrogen domestically to meet industrial decarbonization goals, whereas the EU actively promotes cross-border hydrogen trade and seeks to import 10 million tons of renewable hydrogen by 2030.
4. Different approaches to hydrogen market risk: Both the UK and EU recognize offtake risk as a major barrier to hydrogen project bankability. However, the UK mitigates this through long-term fixed-price contracts (CfDs), while the EU relies on competitive auction mechanisms to determine subsidy levels, leading to more market-driven pricing volatility.

5.4. Germany

Germany is at the forefront of hydrogen offtake structuring in the EU, largely due to its industrial base and H2Global, an auction-based support mechanism designed to facilitate competitive hydrogen procurement and price stabilization. The country's hydrogen strategy emphasizes a two-pronged approach—securing supply through government-backed auctions and incentivizing long-term offtake agreements within key industrial sectors.

5.4.1. H2Global Auction Model for Hydrogen Contracts

Germany's H2Global mechanism operates as an intermediary entity that purchases renewable hydrogen (or derivatives like ammonia, methanol, and SAF) via long-term contracts and resells it on shorter-term contracts to end users. This model ensures price stability and mitigates risk for both hydrogen producers and industrial buyers.

- The H2Global Foundation auctions long-term purchase contracts (10 years) for hydrogen or hydrogen-derived products from global producers at the lowest possible price.

- On the demand side, H2Global resells the acquired hydrogen in shorter-term contracts (e.g., 3–5 years) at a price determined by the market.
- The German government bridges the price gap between the supply and demand auctions using subsidies, ensuring that producers are protected from market volatility while industrial offtakers benefit from competitive pricing.

This mechanism is crucial for de-risking first-mover hydrogen projects, allowing companies to secure stable offtake agreements without exposure to unpredictable price swings.

Fixed-Price and Indexed Contracts for Offtakers

Germany's hydrogen offtake contracts incorporate two primary pricing structures:

1. Fixed-Price Agreements – Under these contracts, hydrogen is sold at a pre-determined price over the contract duration, ensuring revenue predictability for project developers. While these agreements enhance bankability, they pose risks in the event of a significant decline in hydrogen production costs over time.
2. Indexed Contracts – These agreements link hydrogen pricing to external benchmarks such as natural gas, electricity prices, or carbon pricing schemes (ETS allowances). Indexed contracts mitigate risk for offtakers by aligning pricing with broader energy markets but can be less favorable for producers if market dynamics shift unpredictably.

Role of German Industries in Securing Long-Term Agreements

- Heavy industry (chemicals, steel, and refining) is the primary hydrogen offtaker in Germany, given its decarbonization targets and reliance on hydrogen as a feedstock.
- Companies like Thyssenkrupp, BASF, and ArcelorMittal have signed long-term offtake agreements with hydrogen producers, leveraging government-backed subsidies.
- The transport sector is emerging as a major hydrogen user, with the expansion of hydrogen fueling infrastructure and partnerships between hydrogen producers and mobility providers (such as Deutsche Bahn for rail applications).
- Public-private initiatives like HySupply and HyPerformer are enabling regional hubs to create localized hydrogen demand structures.

Table 8: H2Global Summary

Category	Details
Main Offtake Model	H2Global auction system with government-backed price stabilization
Pricing Structures	Fixed-price contracts, Indexed contracts (linked to ETS, electricity, or fossil fuels)
Key Industrial Offtakers	Steel (Thyssenkrupp, Salzgitter), Chemicals (BASF, Linde), Transport (Deutsche Bahn, heavy-duty vehicle manufacturers)
Government Support	Direct subsidies through H2Global, state aid for industrial projects, carbon contracts for difference (CCfDs)
Offtake Contract Duration	Long-term (10 years) for supply auctions, shorter-term (3–5 years) for demand resale
Challenges	High reliance on government intervention, regulatory uncertainty on hydrogen imports, evolving cost structures impacting indexed contracts

Key Takeaways: Germany vs. European Initiatives

1. H2Global provides a structured auction-based offtake model, whereas broader EU initiatives rely more on competitive grant funding and Contracts for Difference (CfDs).

- H2Global introduces a dual-auction system that ensures price stability for both producers and offtakers. In contrast, the European Hydrogen Bank (EHB) operates through competitive auctions, but without a government-backed resale mechanism, leaving more exposure to market volatility.
- The EU's Innovation Fund and Important Projects of Common European Interest (IPCEI) focus on direct subsidies to early-stage projects, while H2Global facilitates real market transactions between producers and industrial buyers.

2. Germany’s fixed-price and indexed contracts provide clarity for investors, but risk long-term price misalignment.

- Compared to EU-wide initiatives, Germany’s indexed contracts tied to energy markets (such as ETS pricing and electricity costs) offer a hedge against long-term price uncertainty.
- EU funding instruments, including Contracts for Difference (CfDs), follow a more market-oriented approach, where support mechanisms compensate for cost differentials rather than fixing prices outright.

3. Industrial demand in Germany acts as a major pull factor, aligning with EU industrial hydrogen strategies.

- Germany’s large-scale hydrogen-consuming industries (e.g., steel, refining, and chemicals) drive long-term hydrogen demand. This aligns with the EU’s Hydrogen Valleys approach, which focuses on regional industrial clusters as anchor off-takers.
- The EU's Fit for 55 and REPowerEU strategies aim to create cross-border hydrogen demand, whereas Germany’s model focuses more on domestic industrial demand aggregation.

4. Germany’s H2Global model could serve as a scalable blueprint for other EU countries.

- H2Global has already gained interest as a potential EU-wide model for hydrogen procurement, particularly in addressing price uncertainty.
- While the European Hydrogen Bank (EHB) aims to bridge the gap between production and demand, the absence of a structured resale mechanism means that Germany’s approach may offer greater revenue certainty for investors.

While H2Global has been widely acknowledged for its structured and transparent approach to hydrogen price stabilization, industry participants during the March 2025 Berlin stakeholder session raised concerns about the scale and adaptability of the program. Companies emphasized that, although H2Global provides useful risk mitigation, the current funding allocation remains insufficient for the needs of large-scale industrial projects. Several participants noted that the mechanism’s focus on 10-year supply and 3–5-year resale contracts may not align with the long-term offtake horizons required for capital-intensive applications, such as sustainable aviation fuel (SAF) and e-methanol production. Others suggested that the program could be enhanced by introducing greater flexibility in contract duration, broader eligibility for domestic producers, and expanded sectoral coverage to include smaller offtakers. Expanding H2Global’s scale and mandate could also allow it to function more effectively as a buyer-of-last-resort or central market-making mechanism, similar to the US H2Hubs approach. This would enhance investor confidence and address some of the structural bankability gaps identified across EU projects.

Several stakeholders expressed that while H2Global represents a promising intervention for early-stage hydrogen market development, its scope and design do not yet meet the scale or certainty requirements of large industrial offtakers. A recurring theme in the discussion was the need for stronger price certainty instruments. Many stakeholders emphasized that the current model—offering 10-year supply contracts with shorter resale windows—falls short of the long-term horizons required to underwrite debt or equity investments in capital-intensive hydrogen projects. Participants advocated for either the extension of contract durations or the layering of additional financial instruments such as contracts for difference (CfDs) or indexed floor-price guarantees to reduce exposure to price volatility. There was also a suggestion to broaden the remit of H2Global so it could serve not only as a contract clearinghouse, but as a more active price-setting or market-making agent. This would better align the mechanism with the bankability requirements of producers, infrastructure developers, and financiers.

5.5. France

France has adopted a more integrated, state-driven approach to hydrogen deployment, embedding hydrogen demand creation within industrial strategies and public-private partnerships. The government has allocated €9 billion under its National Hydrogen Strategy to support both production and offtake mechanisms, ensuring that demand is anchored in transportation, heavy industry, and energy storage applications.

National Hydrogen Strategy's Impact on Offtake Agreements

France's National Hydrogen Strategy (Stratégie Nationale Hydrogène), launched in 2020, has set ambitious targets for hydrogen use in industrial decarbonization and transport. The government provides direct contracts-for-difference (CfDs) subsidies, which cover the cost gap between fossil-based hydrogen and renewable hydrogen, ensuring industrial buyers can secure hydrogen at competitive prices.Hydrogen Industry Offtake Development Plan mandates long-term offtake agreements for strategic industries, including refining and steel manufacturing.

- The ADEME Hydrogen Fund provides capital support and offtake incentives for large-scale industrial projects.
- The government prioritizes hydrogen consumption within existing state-owned infrastructure, such as SNCF (rail) and EDF (energy), which serve as anchor offtakers for early projects.

Role of Public-Private Partnerships in Securing Demand

France has emphasized public-private partnerships (PPPs) as a tool to build long-term hydrogen demand, fostering collaboration between industry leaders and state-backed financial institutions.

- Public-private funding is used to de-risk offtake contracts, ensuring industrial buyers receive price stability.
- The Hydrogen Infrastructure Fund (co-managed by CDC and ADEME) provides long-term support for offtake commitments, ensuring that project developers can secure stable revenues.
- Industrial clusters such as HyAMMED (hydrogen for the Mediterranean region) and H2V (Hydrogen Valleys initiative) support regionalized demand aggregation.

Integration of Hydrogen into Transport and Heavy Industry

1. Transport: The government has mandated the integration of hydrogen into public transport fleets, heavy-duty trucking, and aviation (Airbus ZeroE initiative).

2. Steel & Chemicals: French industrial giants like Air Liquide and TotalEnergies have committed to hydrogen-based feedstock replacement, ensuring long-term demand.
3. Power Sector: EDF and Engie are investing in hydrogen storage applications, creating a secondary demand stream beyond industrial use.

Table 9: French interventions in Hydrogen Market

Category	Details
Main Offtake Model	Public-private partnerships (PPPs), State-backed industrial agreements
Pricing Structures	CfDs (state-backed price guarantees), Indexed contracts for industrial users
Key Industrial Offtakers	Steel (ArcelorMittal), Chemicals (Air Liquide), Transport (SNCF, Airbus)
Government Support	ADEME Hydrogen Fund, Infrastructure Fund (CDC & ADEME), Contracts for Difference (CfDs)
Offtake Contract Duration	10–15 years for industrial users, 5–10 years for transport applications
Challenges	High subsidy reliance, regulatory complexities in hydrogen certification, slower adoption compared to Germany

Key Takeaways: France vs. European Initiatives

1. France’s reliance on public-private partnerships (PPPs) provides strong state-backed offtake certainty, whereas EU mechanisms prioritize competitive auctions. France’s Hydrogen Infrastructure Fund and ADEME-backed initiatives provide long-term financing stability, ensuring offtake security for industrial projects. EU mechanisms such as the EHB and Innovation Fund rely on competitive pricing mechanisms, where subsidies are allocated based on cost-efficiency rather than strategic industrial alignment.
2. France’s Contracts for Difference (CfDs) for hydrogen are more state-led compared to the EU’s auction-based approach. The French CfD mechanism directly supports price stabilization for industrial buyers, reducing offtake risk for early projects The EU’s CfD approach (as proposed within the European Hydrogen Bank) is more market-driven, ensuring cost efficiency but leaving greater exposure to competitive bidding processes. France’s transport integration strategy aligns with the EU’s Fit for 55 and REPowerEU goals.
   - The French government mandates hydrogen integration in aviation, rail, and maritime sectors, ensuring a stable market for hydrogen within national infrastructure.

- These efforts align with EU-wide policies such as ReFuelEU Aviation and FuelEU Maritime, which set targets for RFNBO integration in transport.

3. France’s approach ensures stable industrial demand, but EU initiatives offer greater cross-border scalability.
   - France’s industrial hydrogen strategy focuses on securing domestic offtakers such as ArcelorMittal (steel) and Air Liquide (chemicals), whereas EU initiatives prioritize cross-border hydrogen trade and infrastructure expansion.
   - The EU’s Hydrogen Valleys and IPCEI programs aim to scale hydrogen production across multiple member states, whereas France’s model is more nationally focused on long-term industrial agreements.

5.6. South Korea

South Korea has emerged as a leader in hydrogen adoption, with the Hydrogen Economy Roadmap 2040 serving as the foundation for its ambitious hydrogen market development. The government has set clear targets for hydrogen production, distribution, and consumption, aiming to position South Korea as a global hydrogen economy hub. A central pillar of this roadmap is securing long-term offtake agreements through corporate power purchase agreements (PPAs), industrial-scale commitments, and government-backed price stabilization mechanisms.

Influence of the Hydrogen Economy Roadmap on Offtake Agreements

The Hydrogen Economy Roadmap 2040, introduced in 2019, has set long-term demand commitments across multiple sectors, ensuring stable offtake for hydrogen producers. The roadmap outlines:

- Targeting 5.26 million tons of hydrogen demand by 2040, with heavy industrial and transport sectors serving as major offtakers.
- A national hydrogen supply network, ensuring large-scale adoption by steelmakers, petrochemical companies, and utilities.
- State-backed offtake contracts, where public sector entities and large corporations enter fixed-term agreements with hydrogen producers.

The Korean government plays a direct role in securing offtake commitments, ensuring that domestic industries receive stable hydrogen supply at predictable prices. This reduces offtake risk for investors, making Korean hydrogen projects more bankable than in purely market-driven economies.

Corporate PPAs and Industrial-Scale Offtake Commitments

In Korea, corporate PPAs and industrial hydrogen purchase agreements are playing a crucial role in de-risking hydrogen projects. Major conglomerates such as Hyundai, SK Group, and POSCO have signed long-term offtake agreements to secure clean hydrogen supply for mobility, refining, and steel production.

Key industrial offtake commitments include:

- POSCO's agreement to procure hydrogen for steel production, reducing reliance on coal-based blast furnaces.
- Hyundai's commitment to offtake hydrogen for fuel cell vehicle production and refueling infrastructure.
- SK Group and GS Caltex securing hydrogen offtake for refining and petrochemical processes.

Unlike the EU, where market-driven auctions determine offtake, South Korea's large industrial groups sign direct bilateral contracts with producers. This provides greater long-term certainty but also means that offtake is heavily concentrated among a few dominant industrial players.

Government Subsidies and Long-Term Price Support

A key differentiator in South Korea's hydrogen market is the direct involvement of the government in price stabilization. The government uses subsidies, price floors, and tax incentives to:

- Guarantee a minimum price for hydrogen, ensuring producer viability.
- Offer subsidies for offtakers, particularly in heavy industry and transport sectors, to offset high initial costs.
- Reduce the cost gap between hydrogen and fossil fuels for industrial adoption.

The Korean government has established price support mechanisms similar to CfDs seen in the EU, ensuring producers receive a stable revenue stream even if market conditions fluctuate. However, unlike the EU's competitive auction-based approach, South Korea's subsidy model is more centrally controlled and targeted toward key industrial players.

Table 10: Comparing Korean and EU interventions in the Hydrogen market

Key Factor	South Korea	European Union
Offtake Model	Government-backed fixed contracts with industrial players	Market-driven auctions (e.g., European Hydrogen Bank)
Price Mechanism	Direct subsidies, price floors, and CfD-style support	Competitive bidding mechanisms, CfDs for price stabilization
Demand Drivers	Heavy industry, refining, transport (led by chaebols like Hyundai, SK, POSCO)	Cross-border trade, industrial clusters, decentralized hydrogen hubs
Government Role	Direct price support, minimum price guarantees	Indirect market shaping through auctions and grants
Challenges	Market concentration, reliance on large corporate offtakers	Market volatility, fragmented regulatory landscape

Key Takeaways: South Korea vs. European Hydrogen Offtake Models

1. South Korea adopts a more centralized approach to hydrogen offtake compared to the EU's market-driven mechanisms. The Korean government plays a direct role in

ensuring long-term offtake agreements, whereas the EU relies on market competition to allocate subsidies and secure demand.

2. Industrial giants drive hydrogen demand in Korea, while the EU's focus is on cross-border trade and decentralized hydrogen hubs. South Korea's offtake market is dominated by chaebols (large conglomerates) such as Hyundai, SK, and POSCO, which sign long-term bilateral contracts. The EU prioritizes creating interconnected hydrogen markets, supporting both domestic consumption and international trade.
3. Korea's price support mechanisms reduce offtake risk, but market concentration could limit competition. Price stabilization tools (subsidies, minimum prices) ensure producers receive stable revenues, improving project bankability. However, reliance on a few large offtakers could stifle competition and limit opportunities for new entrants.
4. The EU's auction-based approach offers competitive cost reduction but exposes producers to price fluctuations. Korea's fixed-price support model protects early adopters but could become expensive for the government in the long run. The EU's competitive auctions incentivize cost reductions, but producers face higher revenue uncertainty due to market fluctuations.
5. Lessons for Europe: Korea's long-term offtake model could offer stability for early-stage hydrogen projects. The EU could consider hybrid approaches that blend market competition with strategic offtake guarantees, particularly for critical industries like steel and refining.

5.7. Japan

Japan's Hydrogen Offtake Mechanisms

Japan has positioned itself as a global leader in hydrogen adoption, with clear long-term strategies and public-private partnerships driving offtake commitments. The country's Basic Hydrogen Strategy, first introduced in 2017 and revised in 2023, outlines ambitious hydrogen deployment targets, focusing on industrial-scale offtake agreements, international hydrogen trade, and government-backed price stability mechanisms.

Influence of the Basic Hydrogen Strategy on Offtake Agreements

The Japanese government has set explicit demand-side targets to stimulate hydrogen consumption:

- 20 million tons of hydrogen demand by 2050, covering industrial processes, transport, and power generation.
- Expansion of hydrogen supply chains, ensuring secure long-term procurement agreements with domestic and international producers.
- Strong reliance on blue and green hydrogen imports, particularly from Australia, the Middle East, and North America.

Japan's offtake strategy is closely linked to its energy security goals, given its limited domestic renewable resources. This differs from the EU approach, where hydrogen production is more distributed across various Member States.

Corporate Hydrogen PPAs and Industrial Offtake Commitments

Japan's major industrial conglomerates—including Toyota, Kawasaki Heavy Industries, Mitsubishi, and JERA (Japan's largest power generator)—are leading long-term hydrogen offtake agreements. These agreements typically involve:

- Hydrogen supply for power generation, including large-scale hydrogen co-firing in thermal power plants.
- Hydrogen use in steelmaking, particularly through projects led by Nippon Steel and other heavy industries.
- Fuel cell development and mobility applications, where Toyota and Honda have signed hydrogen procurement contracts.

Japan encourages industrial players to enter long-term PPAs, ensuring predictable revenue streams for hydrogen developers. This is similar to South Korea's model but differs from the EU, which leans more on competitive auction mechanisms.

Government Subsidies and Price Stability Mechanisms

To ensure hydrogen affordability, Japan provides direct financial support through mechanisms such as:

- Subsidies for hydrogen buyers, reducing the price gap between hydrogen and fossil fuels.
- Government-backed fixed-price offtake agreements, ensuring predictable costs for industrial users.
- International hydrogen procurement incentives, securing long-term supply agreements with key trading partners.

Japan is also exploring a hydrogen CfD mechanism, similar to the EU's Contracts for Difference model, to stabilize long-term hydrogen pricing. However, the Japanese approach is more centrally coordinated, with direct government involvement in structuring offtake agreements.

Table 11: Comparing Japanese and EU Interventions in the Hydrogen market

Key Factor	Japan	European Union
Offtake Model	Government-backed long-term agreements with industrial players	Market-driven auctions (e.g., European Hydrogen Bank)
Price Mechanism	Direct subsidies, fixed-price agreements, CfD-style support	Competitive bidding mechanisms, CfDs for price stabilization

Demand Drivers	Power generation, industrial steelmaking, automotive fuel cells	Cross-border trade, industrial clusters, decentralized hydrogen hubs
Government Role	Direct financial support, subsidies for hydrogen buyers	Indirect market shaping through auctions and grants
Challenges	Heavy reliance on hydrogen imports, limited domestic production	Market volatility, fragmented regulatory landscape

Key Takeaways: Japan vs. European Hydrogen Offtake Models

1. Japan's government plays a stronger role in structuring long-term offtake agreements, while the EU relies on market-driven auctions.
2. Japan's strategy focuses on securing hydrogen imports, whereas the EU aims to balance domestic production with cross-border trade.
3. Both regions see industrial offtakers as critical, but Japan's approach offers stronger price guarantees to encourage hydrogen adoption.

5.8. China

China leads the world in hydrogen production and consumption, but its offtake market is evolving differently compared to Europe. The government's Five-Year Plans and long-term industrial policies prioritize state-backed hydrogen procurement, large-scale demonstration projects, and state-owned enterprise (SOE) involvement in offtake agreements.

Influence of China's National Hydrogen Strategy on Offtake Agreements

China's hydrogen offtake market is primarily driven by state planning rather than market competition. Key government targets include:

- Annual hydrogen production reaching 200,000 tons of green hydrogen by 2025.
- Large-scale adoption in heavy industry, refining, and long-haul transport.
- Expansion of pipeline and storage infrastructure, improving hydrogen logistics.

Unlike the EU, which uses competitive auctions, China relies on SOEs to act as guaranteed offtakers, ensuring demand for hydrogen projects.

SOE-Led Offtake Agreements and Industrial Adoption

China's hydrogen market is dominated by state-owned enterprises, which sign long-term hydrogen procurement contracts with both domestic and international suppliers. Key examples include:

- Sinopec's commitment to green hydrogen for refining and industrial use.
- Baowu Steel's hydrogen-based steelmaking pilot projects.

- China National Petroleum Corporation (CNPC) integrating hydrogen into its energy mix.

These agreements de-risk hydrogen investments, as SOEs are seen as reliable offtakers with strong government backing.

Government Subsidies and Offtake Price Support

China's approach to hydrogen price stabilization includes:

- Direct government subsidies for hydrogen producers and offtakers.
- Fixed-price contracts for SOE-led hydrogen projects.
- Regional hydrogen hubs, where provincial governments commit to purchasing hydrogen at pre-agreed prices.

Unlike the EU's competitive pricing structure, China's hydrogen prices are often administratively set, ensuring stable demand but limiting market transparency.

Table 12: Comparing Chinese and EU Interventions in the Hydrogen market

Key Factor	China	European Union
Offtake Model	State-owned enterprises (SOEs) as guaranteed offtakers	Market-driven auctions (e.g., European Hydrogen Bank)
Price Mechanism	Government-set prices, direct subsidies	Competitive pricing, CfDs, subsidy auctions
Demand Drivers	Heavy industry, refining, state-led transport projects	Industrial clusters, renewable hydrogen market development
Government Role	Direct involvement, state-led procurement	Indirect market shaping through competitive auctions
Challenges	Lack of market transparency, reliance on state-owned enterprises	Market volatility, fragmented regulatory landscape

Key Takeaways: China vs. European Hydrogen Offtake Models

China's hydrogen offtake market is state-driven, while the EU's relies on competitive market pricing. In China, state-owned enterprises serve as guaranteed offtakers, whereas the EU relies on corporate buyers competing in auctions.

1. Price stability is stronger in China, but market transparency is higher in the EU.
2. China's government fixes hydrogen prices to support offtakers, while the EU lets market competition determine pricing through auctions.
3. EU hydrogen markets are more decentralized, while China's offtake is heavily concentrated among SOEs.

In Europe, offtake contracts involve multiple industrial clusters, whereas in China, a few state-backed firms dominate procurement. China's hydrogen adoption is rapid due to central government coordination, but private sector participation remains limited. The EU approach encourages private sector participation, making it more attractive to international investors.

While this is a matter of debate, China's SOE-led offtake model provides strong price stability and demand certainty, but limits market competition. In contrast, the EU's competitive auction model fosters a dynamic hydrogen economy but introduces revenue uncertainty for producers. It might be said that China's state-backed approach accelerates hydrogen deployment, but that the EU's market-driven model may provide greater long-term sustainability, particularly for cross-border hydrogen trade and investment.

5.9. Spain

Spain is rapidly emerging as a leading player in the European hydrogen market, driven by strategic investments, public-private partnerships, and robust infrastructure development. The country's hydrogen initiatives are closely aligned with EU objectives but also incorporate national strategies tailored to Spain's abundant renewable energy resources and industrial demand. The Spanish government, through its Hydrogen Roadmap and state-backed entities like Enagás, is facilitating large-scale projects and securing long-term offtake agreements to de-risk investments and stimulate market growth.

Strategic Investments in Hydrogen Infrastructure

The Spanish government and key industrial stakeholders have committed substantial resources to hydrogen infrastructure development. Enagás, Spain's state-owned gas utility, is spearheading efforts to transition from traditional natural gas operations to renewable hydrogen. In February 2025, Enagás announced plans to invest over €4 billion by 2030, with €3.13 billion dedicated to hydrogen infrastructure. These funds will support:

- The Spanish Hydrogen Backbone, which integrates domestic hydrogen production and consumption.
- The H2Med Corridor, a trans-European hydrogen pipeline linking Spain and Portugal to France and broader European markets.

The H2Med project, the first dedicated green hydrogen corridor in Europe, has attracted interest from 170 companies, proposing over 500 projects. This highlights the strong market demand for Spanish hydrogen and positions the country as a major export hub.

Public-Private Partnerships and Industrial Offtake Agreements

Spain's hydrogen offtake strategy is characterized by long-term agreements between producers and industrial consumers, ensuring stable demand and financial viability for new projects.

Key initiatives include:

1. Enagás-Led Offtake Agreements

- Enagás has facilitated public-private partnerships to secure industrial demand for hydrogen, with agreements focusing on heavy industry, refining, and synthetic fuel production. The company plays a critical role in enabling Spain's decarbonization goals by integrating hydrogen infrastructure with existing gas networks.

2. The Catalina Project

- A €1.7 billion investment in a 500 MW green hydrogen facility powered by 1.1 GW of onshore wind and solar. Hydrogen produced will be transported through a 221 km pipeline to a fertilizer plant, enabling a shift from grey to green ammonia.
- The project is backed by Copenhagen Infrastructure Partners (CIP) and Enagás, showcasing Spain's ability to attract foreign investment.

3. Iberostar Hydrogen Integration in Tourism

- The Iberostar Group became the first tourism company in Spain to incorporate green hydrogen into its operations, with support from ACCIONA Energía and Enagás. Hydrogen produced at the Lloseta plant in Mallorca replaces 2-5% of Iberostar's natural gas consumption, contributing to the company's 2030 carbon neutrality goal.

The Role of Spain's Public Hydrogen Tenders

Spain has begun implementing public offtake tenders through state-owned utilities to guarantee demand for hydrogen projects. The Ministry for Ecological Transition and the Demographic Challenge (MITECO), in collaboration with Enagás, is leading these efforts. Key developments include government-backed hydrogen auctions, modeled after the EU Hydrogen Bank, aim to allocate subsidies for hydrogen production.

They also include long-term price support mechanisms, such as fixed-price contracts and indexed pricing, are being explored to provide financial certainty to investors and integration with existing gas networks, allowing for hydrogen blending and facilitating a smoother transition for industrial consumers.

Table 13: Spain's hydrogen interventions

Key Factor	Spain	European Union
Offtake Model	Government-led initiatives and strategic public-private partnerships securing long-term agreements.	Market-driven auctions (e.g., European Hydrogen Bank) to allocate subsidies and secure demand.
Price Mechanism	Direct investments and funding to reduce production costs and incentivize adoption.	Competitive bidding mechanisms, Contracts for Difference (CfDs) for price stabilization.
Demand Drivers	Industrial decarbonization, particularly in refining, fertilizer production, and tourism sectors; development of hydrogen corridors.	Cross-border trade, industrial clusters, and decentralized hydrogen hubs.

Government Role	Active involvement through funding, infrastructure development, and facilitating strategic partnerships.	Indirect market shaping through policy frameworks, regulations, and financial instruments.
Challenges	Ensuring regulatory stability to attract investment; scaling infrastructure to meet production and export goals.	Harmonizing regulations across member states; managing market volatility and ensuring sufficient demand.

Key Takeaways: Spain vs. European Hydrogen Offtake Models

Spain's hydrogen offtake mechanisms demonstrate a structured, state-backed approach, integrating public-private partnerships, industrial commitments, and strategic infrastructure investments. While the EU relies more on market-based auctions and competitive bidding, Spain's model ensures demand certainty and financial stability, making it a leader in Europe's emerging hydrogen economy. By securing long-term offtake agreements, Spain is well-positioned to drive industrial decarbonization, export growth, and hydrogen market integration across Europe with the following distinguishing characteristics:

1. Proactive Investment Approach: Spain employs a state-led investment model, contrasting with the EU's broader market-based mechanisms. Enagás plays a critical role in securing industrial offtake.
2. Strategic Public-Private Partnerships: Spain leverages direct offtake agreements with industrial players like Iberostar, fertilizer plants, and heavy industry, ensuring immediate demand stability.
3. Infrastructure-Centric Strategy: The H2Med Corridor and Hydrogen Backbone align with EU objectives but position Spain as a key hydrogen exporter.
4. Regulatory Considerations: Spain must ensure long-term policy stability to attract foreign investment and maintain competitiveness within the broader EU hydrogen ecosystem.

5.10. Key Learnings from Global Hydrogen Offtake Mechanisms and Implications for EU Policy Development

A comparative analysis of hydrogen offtake mechanisms across global markets reveals several critical insights that can shape future European Union (EU) interventions. The success of hydrogen market development depends on a combination of financial instruments, risk mitigation strategies, and policy frameworks that balance supply- and demand-side dynamics.

Countries like the United States and South Korea adopt more interventionist approaches, directly subsidizing offtake through mechanisms such as Contracts for Difference (CfDs), tax credits, and hydrogen hubs with dedicated long-term funding. Meanwhile, European initiatives primarily focus on market-driven competitive auctions through the European Hydrogen

Bank. A hybrid approach that blends elements of direct subsidies with structured market mechanisms could improve project bankability and accelerate adoption.

The hydrogen offtake risk remains a key barrier to investment, particularly in emerging markets where industrial demand has yet to materialize at scale. Long-term fixed-price contracts, as seen in Japan and Germany, offer a clear precedent for mitigating financial uncertainty. The EU could consider sectoral offtake guarantees or demand aggregation platforms to enhance revenue predictability for developers.

In France and Spain, the integration of hydrogen into transport, industrial clusters, and public-private partnerships has supported early adoption. Germany's H2Global model ensures demand certainty by acting as an intermediary between producers and industrial users. A similar pan-European mechanism could streamline investment and reduce cross-border regulatory friction.

South Korea and the UK have explored innovative financing models that blend CfDs with corporate power purchase agreements (PPAs) to hedge against long-term price volatility. The EU could leverage hybrid models that combine capacity-based incentives with indexed pricing mechanisms to attract private sector capital while ensuring financial sustainability.

Countries like China and the United States focus on regional hydrogen hubs and supply chain integration, ensuring that production is matched with infrastructure development. The EU must complement its auction-based funding with coordinated investments in hydrogen storage, transportation, and industrial applications to avoid stranded assets and unlock economies of scale.

Implications for Future EU Hydrogen Interventions

Given the need for accelerated hydrogen market development in Europe, a multi-faceted strategy is required to bridge the gap between ambitious production targets and commercial-scale offtake commitments. Future interventions could include:

- Hybrid financing models combining CFDs with PPAs to reduce price risk while allowing corporate buyers to play a larger role in market development.
- Demand aggregation platforms and buyer consortia to facilitate long-term supply agreements, particularly for industries like steel, chemicals, and transport.
- Capacity-based incentives for early adopters to lower the cost burden of transitioning to hydrogen.[1]
- Sector-specific offtake guarantees in industries where hydrogen adoption is most critical, ensuring minimum revenue floors for producers.
- Hydrogen-as-a-service business models to de-risk infrastructure investments by offering bundled production, storage, and delivery solutions.

[1] One emerging strategy to address fragmented demand and improve offtake certainty is the formation of hydrogen buyer alliances or consortia. These groups, composed of industrial users, transport operators, utilities, and municipalities, aim to pool hydrogen demand and jointly procure clean hydrogen via coordinated tendering or long-term contracts. Such platforms lower transaction costs for smaller buyers, increase contract volumes for producers, and enhance bankability through aggregated creditworthiness. In addition, they can act as a focal point for standardising contract terms and aligning quality or certification requirements, thereby reducing friction in the offtake market.

6. Ideas for further Interventions for Enhancing Hydrogen Offtake Agreements in Europe

Table 14: Ideas for Interventions

Intervention Name	Intervention Description	Financing Instrument Type & Nature	Key Problem it Solves	Likely Beneficiaries & Hydrogen Project Type	Legal Counterparty	Key Implementation Challenges	Legal & Financial Terms Contributing to Bankability
Hybrid financing models combining CFDs with PPAs	Combining Contracts for Difference (CFDs) with long-term Power Purchase Agreements (PPAs) to de-risk projects while allowing some market flexibility.	CFD with fixed or indexed pricing + PPA-backed offtake agreements (Commercial & Concessional financing).	Addresses price uncertainty and ensures long-term revenue stability while allowing partial exposure to market pricing.	Large industrial hydrogen consumers (e.g., steel, chemicals) and renewable hydrogen producers developing projects >100MW.	Hydrogen producers, EU Hydrogen Bank, national governments, industrial buyers.	Requires coordination between government-backed CFDs and private offtake agreements; potential legal conflicts between subsidy rules and commercial contracts.	Guarantees a minimum revenue floor for developers while enabling partial upside exposure, making projects more attractive to lenders and improving Debt Service Coverage Ratios (DSCRs).
Demand aggregation platforms and buyer consortia	Establishment of centralized buyer consortia or digital marketplaces to pool demand across multiple offtakers.	Structured buyer groups, publicly backed demand contracts (Commercial & Concessional financing).	Reduces offtaker fragmentation, allowing smaller industrial users to secure hydrogen without long-term commitments.	Medium-sized industrial firms, transport operators, public sector energy users requiring 5,000–50,000 tons of H_2 annually.	National governments, energy agencies, trade associations.	Physical delivery challenges may limit applicability to niches with similar infrastructure. Requires coordination between multiple offtakers with different risk appetites; ensuring fair pricing and equitable contract terms.	Improves DSCRs by creating a more predictable demand base, but creditworthiness of multiple buyers must be ensured to avoid default risk. May require credit guarantees or partial offtake commitments from public entities.

Capacity-based incentives for early adopters	Offering financial incentives based on installed hydrogen production capacity rather than output, ensuring revenue certainty in early project stages.	Grant-based CAPEX support, concessional loans, capacity-based payments (Concessional financing).	Solves demand risk for early projects by ensuring fixed payments regardless of utilization rates.	Hydrogen production developers in early-stage projects (10–100MW) lacking confirmed offtakers.	National hydrogen regulators, public sector funding agencies.	May distort market pricing if incentives continue beyond necessary support period; ensuring fair allocation mechanisms.	Helps secure debt financing by guaranteeing a minimum revenue stream independent of output, allowing developers to raise debt more easily even before securing stable offtake contracts.
Sector-specific offtake guarantees (e.g., steel, chemicals, transport)	Direct government-backed offtake agreements targeting key sectors with high decarbonization potential.	Public procurement-backed contracts, CFD mechanisms with sector-specific pricing support (Concessional financing).	Overcomes reluctance of major industries to transition to hydrogen by ensuring cost parity with fossil alternatives.	Large industrial hydrogen users with high process integration costs (e.g., steelmakers, chemical manufacturers).	EU Commission, industrial trade bodies, national hydrogen agencies.	Ensuring compliance with state aid rules; sector-specific subsidies may create cross-sectoral competitive distortions.	Guarantees long-term demand and supports higher leverage ratios for project financing by securing a strong creditworthy counterparty.
Hydrogen-as-a-service business models	Leasing or service-based agreements i.e. industrial users pay for H2 as a service rather than making capital investments in hydrogen infrastructure.	Service contracts, private investment-backed leasing models (Commercial financing).	Lowers capital barriers for industrial users, encouraging early adoption without large-scale investments.	Small and medium enterprises (SMEs), fleet operators, localized hydrogen hubs needing flexible supply.	Hydrogen infrastructure providers, leasing companies, financial institutions.	Requires innovative financial structuring and risk-sharing models; potential mismatch between supply and demand stability.	Reduces upfront capital investment risk (e.g. for non-traditional H2 users). Lenders may require residual value guarantees on leased infrastructure.

Government-backed market-making mechanism	A public entity acting as an intermediary buyer and seller of hydrogen to stabilize prices and provide liquidity.	Public market stabilization fund, intermediary procurement contracts (Concessional financing).	Addresses market illiquidity by ensuring a guaranteed off-taker and balancing supply-demand mismatches.	Green hydrogen developers, industrial offtakers without direct trading access, hydrogen storage operators.	EU Hydrogen Bank, European Investment Bank, national regulators.	Legal complexity of operating a public procurement entity in competition with private market players.	Offers long-term contracts to stabilize revenue and enhance creditworthiness of projects. A well-funded market-maker can act as a "buyer of last resort"
Carbon Contracts for Difference (CCfDs) for hydrogen	CCfDs covering hydrogen price differentials based on avoided CO_2 emissions cost, ensuring green hydrogen remains competitive.	Government-backed CCfDs linked to ETS carbon pricing (Concessional financing).	Offsets the cost gap between green hydrogen and fossil hydrogen, ensuring cost competitiveness.	Energy-intensive industries with high CO_2 emissions looking to transition (e.g., ammonia, cement, shipping).	EU Commission, national energy regulators.	Requires predictable ETS pricing structure; difficult to balance contract values over time.	Provides long-term revenue security, reducing investor risk. Banks may require state-backed repayment guarantees to hedge against market volatility.
Hydrogen reserve auctions	Auction-based hydrogen reserve system where producers secure capacity commitments with flexible delivery schedules.	Publicly funded reserve capacity payments, auction clearing mechanisms (Concessional financing).	Addresses supply uncertainty by ensuring pre-agreed delivery schedules and preventing stranded assets.	Large hydrogen production developers investing in gigawatt-scale projects (>500MW).	EU Hydrogen Bank, project financiers, energy agencies.	May require significant state intervention in the short term; ensuring fair access for smaller players.	Facilitates large-scale investment planning by reducing offtake risk. Auctions enable more favorable debt terms for large hydrogen projects.

6.1. Additional Considerations on Physical Delivery and Debt Service Implications

Physical Infrastructure Limitations in Demand Aggregation Platforms: Unlike digital marketplaces for electricity or natural gas, hydrogen requires specialized transportation and storage solutions. Demand aggregation is only viable in niches where physical delivery infrastructure is consistent—such as urban hydrogen refueling networks, industrial clusters with pipeline networks, or maritime transport hubs. For dispersed users, the cost of logistics and storage can erode the financial benefits of aggregation.

6.2. Bankability and Hydrogen Offtake Risks:

- Higher DSCRs are required in early-stage hydrogen projects due to offtake uncertainty. Lenders may require ratios exceeding 1.5x for greenfield projects until the market stabilizes.
- Role of creditworthy offtakers in reducing borrowing costs: Government-backed offtake contracts (e.g., CCfDs, sectoral guarantees) lower financing risk, allowing developers to secure debt at better terms.
- Revenue stabilization mechanisms: Interventions like CFDs, CCfDs, and government-backed buyer-of-last-resort schemes provide predictable revenue streams, making projects more attractive to debt providers.

6.3. Open Questions and Policy Considerations

1. Harmonization with National Hydrogen Strategies: Should the EU implement these measures centrally, or should individual member states be allowed to tailor mechanisms based on national industrial policies?
2. Integration with Existing Infrastructure Plans: Are physical delivery limitations fully addressed in current policy frameworks, or do infrastructure investments (pipelines, storage, transport hubs) need to be prioritized alongside offtake incentives?
3. Market-based vs. Interventionist Approaches: To what extent should the EU intervene to set offtake prices and guarantee demand? How can market-driven solutions (e.g., voluntary aggregation platforms) be balanced with government-backed mechanisms?
4. Cross-border Coordination and Legal Risks: Would an EU-level market-making entity face legal challenges related to competition law, WTO trade rules, or state aid regulations?
5. Cross-Sector Offtake Flexibility and Allocation Rights: Stakeholders in the Berlin session emphasized the need for offtake structures that allow hydrogen buyers to allocate contracted volumes across multiple use cases or entities within a group — such as between industrial sites, subsidiaries, or mobility applications. Current offtake contract designs are often rigid, tying hydrogen supply to a single application, which reduces operational efficiency and undermines commercial case viability. Such flexibility (say across industries or industrial sites) can also promote economies of scale in hydrogen procurement and foster cross-sectoral decarbonisation coordination.

Appendix One

Clarifying the CFD and PPA Combination Proposal

The idea of combining Contracts for Difference (CFDs) and Power Purchase Agreements (PPAs) is not entirely new—many national-level hydrogen incentive schemes already integrate elements of both mechanisms. However, the proposed enhanced combination seeks to structure these agreements in a way that maximizes bankability while addressing gaps that current national schemes may not fully cover.

How the CFD-PPA Combination Works

The proposed Hybrid CFD-PPA Model creates a structured two-tier revenue mechanism to provide price stability, de-risk offtake commitments, and enhance lender confidence for hydrogen projects.

Structure of Agreements

Contract for Difference (CFD) – Public Counterparty (Government / Hydrogen Bank)

1. Objective: Provides minimum guaranteed revenue to the hydrogen producer, ensuring a stable return on investment and protecting against price volatility.
2. Mechanism: Covers the gap between the hydrogen strike price and market price (or an indexed reference price, if applicable).
3. Counterparty: Typically, a government agency, hydrogen bank, or national energy authority (e.g., the European Hydrogen Bank, UK LCCC, or Germany's H2Global).
4. Coverage Scope: The CFD applies to a portion of production volume—typically 50%-75%, ensuring that the project is bankable but still allows some exposure to the market.

Power Purchase Agreement (PPA) – Private Counterparty (Industrial Buyer / Utility)

Objective: Provides a direct commercial revenue stream from offtakers purchasing hydrogen.

Mechanism: If the renewable electricity supply is external, a PPA with a renewable generator secures the project's power supply at a stable price. If the renewable power plant is part of the hydrogen project, a corporate PPA between the hydrogen producer and the industrial offtaker secures sales of both electricity and hydrogen.

Counterparty: Large industrial buyers, utilities, or hydrogen consumers such as steelmakers, chemical producers, and refuelling networks.

Coverage Scope: The remaining 25%-50% of hydrogen production is sold directly under PPAs, allowing some market-driven pricing dynamics.

Key Considerations in Structuring the Model

Isn't This Already Covered by Existing CFD Regimes?

National CFD regimes (UK, Germany, Netherlands) are typically designed for price support only, ensuring producers receive a fixed price per kg of hydrogen. However:

1. They do not always mandate an offtaker relationship, leaving projects at risk of finding end buyers.

2. They may not integrate direct renewable electricity procurement, which is essential for cost stability in green hydrogen.
3. They often cover 100% of production volumes, which may reduce price discovery and market competition.

The Hybrid CFD-PPA Model instead:

- Splits the revenue mix: Government-backed CFDs cover part of the hydrogen supply, while PPAs allow production risk and price risk-based cost, plus pricing for the rest.
- Encourages early commercial offtakers: By requiring a private offtake agreement for a portion of production, industrial users are incentivized to commit to hydrogen.
- Supports renewable integration: If structured well, renewable PPAs can be directly tied to hydrogen production, lowering overall project costs.

Key Questions & Challenges for Implementation

Should the CFD Cover 100% of Production or Only a Portion?

1. A partial CFD model (50%-75%) encourages private offtake contracts while maintaining bankability.
2. A full CFD model (100%) removes all price risk but discourages private sector market development.

How Should Renewable Electricity Be Sourced?

- Inside the hydrogen project (owned RES plant) → More cost control but requires larger CAPEX.
- External procurement via a PPA → Lower risk but exposes the project to power price fluctuations (depends on pricing of PPA – indexed vs fixed).
- Hybrid approach → A mix of self-generation and grid PPAs can balance flexibility and cost certainty.

Would Lenders Accept a Hybrid CFD-PPA Structure?

- Lenders typically prefer stable, contracted revenues (CFDs provide this).
- PPAs introduce some market risk, but if backed by strong industrial creditworthy offtakers, it remains financeable. PPA's also introduce production margin risk depending on single (intermittent supply vs stable supply)
- Debt sizing would depend on the CFD's coverage percentage—higher CFD coverage leads to more leverage.
- How Does This Model Fit with Existing EU and UK Hydrogen Programs?
- EU Hydrogen Bank's pilot auctions already use CFDs, but they could integrate a PPA requirement to drive offtake commitments.
- For example, the UK Low Carbon Hydrogen Agreements (LCHA) already function as CFDs, but they might expand to require industry co-offtake agreements.

Clarification of Hydrogen-as-a-Service Business Model

The hydrogen-as-a-service (HaaS) model presents an innovative solution to reduce the financial and operational barriers for industrial users seeking to adopt hydrogen while creating a predictable revenue stream for suppliers. This approach mirrors leasing or subscription-based models in other industries, such as energy-as-a-service (EaaS) in renewables or mobility-as-a-service (MaaS) in the transport sector.

Contractual Arrangements and Risk Allocation

Under this model, hydrogen suppliers retain ownership of production, storage, and delivery infrastructure while providing hydrogen to customers on a usage-based or subscription basis. The agreements would be structured similarly to power purchase agreements (PPAs) or long-term service contracts in the energy sector, with clear allocation of risks:

Supplier Risks:

- Capital expenditure for infrastructure (electrolysers, storage, pipelines, refueling stations).
- Operational risks related to production uptime and reliability.
- Market price risk if pricing is not fixed.

Offtaker Risks:

- Volume commitment risk (minimum contracted usage).
- Regulatory and compliance risks related to hydrogen standards.
- Potential exposure to long-term price fluctuations, depending on pricing model.

HaaS contracts could also include performance guarantees where suppliers are responsible for ensuring hydrogen availability and quality, while customers are only liable for consumption. This model is particularly attractive for industries with low capital investment capacity but high hydrogen demand, such as logistics, transport, and smaller industrial users.

Pricing Mechanisms

Three potential pricing models could be employed:

1. Fixed Subscription Model – Customers pay a fixed monthly or annual fee based on expected hydrogen usage, similar to capacity payments in power markets.
2. Usage-Based Pricing – A per-kilogram charge based on actual hydrogen consumption, similar to gas or electricity billing.
3. Hybrid Model – A combination of a fixed capacity fee and variable pricing for excess consumption.

These mechanisms ensure that hydrogen consumers avoid large upfront capital investments while suppliers secure a stable and predictable revenue stream, improving bankability.

Real-World Analogues & Case Studies

1. Energy-as-a-Service (EaaS): Companies like Schneider Electric and Siemens offer renewable power as a service, where customers pay for energy usage without owning solar panels or storage infrastructure.
2. Industrial Gas Supply Agreements: Large chemical companies (e.g., Linde, Air Liquide) operate long-term contracts for industrial gases (oxygen, nitrogen, etc.), where users do not invest in production infrastructure but pay for delivered volumes.
3. Battery-as-a-Service (BaaS): Used in the electric vehicle (EV) industry (e.g., NIO in China), allowing users to lease batteries instead of purchasing them outright, lowering initial costs while ensuring continuous energy availability.

Applicability to Hydrogen Markets

The HaaS model could be particularly effective in:

1. Heavy transport & logistics hubs, where fleet operators require reliable hydrogen supply but lack capital for on-site electrolysers or refueling stations.
2. Industrial clusters, where multiple smaller businesses share hydrogen infrastructure, reducing costs through economies of scale.
3. Remote energy applications, where hydrogen is delivered to off-grid locations for power generation.

By shifting hydrogen procurement from a CAPEX-heavy investment to an OPEX-driven service model, the HaaS approach lowers adoption barriers, improves project bankability, and encourages broader industrial uptake. However, regulatory support (e.g., ensuring long-term price visibility, infrastructure sharing agreements) and robust supplier-offtaker contracts will be essential for its success. Further pilot projects and private-public partnerships could provide proof of concept and refine the model’s implementation.

Appendix 2: Hydrogen Derivatives

While the focus of the report has been on pure hydrogen, achieving widespread decarbonization also requires a strategic consideration of hydrogen derivatives. These derivatives – primarily ammonia, methanol, and synthetic fuels – are compounds produced using hydrogen as a key input. They play a crucial role as versatile energy carriers and chemical feedstocks, extending the applicability and reach of hydrogen across various sectors.

Hydrogen derivatives are significant because they overcome key limitations associated with pure hydrogen, particularly regarding transportation and storage. Pure hydrogen, with its low volumetric energy density, presents challenges for efficient and cost-effective long-distance transport. Derivatives like ammonia and methanol offer a more energy-dense form for shipping and distribution, making them attractive options for regions lacking extensive hydrogen pipeline infrastructure.

Furthermore, certain applications are better suited to hydrogen derivatives than pure hydrogen. For example, ammonia is a vital component in fertilizer production, while methanol serves as a building block for a wide range of chemical products. Synthetic fuels, produced by combining hydrogen with captured carbon dioxide, offer a pathway to decarbonize the aviation and maritime sectors, where direct electrification is challenging.

Therefore, the successful deployment of hydrogen derivatives is inextricably linked to the development of a thriving hydrogen economy. By enabling easier transport, storage, and utilization of hydrogen in diverse sectors, derivatives expand the market potential for green hydrogen and contribute to a more resilient and sustainable energy system. The subsequent sections will explore each of these key derivatives in more detail, outlining their production pathways, applications, and the policy support needed to unlock their full potential.

Ammonia (NH_3): A Versatile Hydrogen Carrier and Industrial Feedstock

Production Pathways

Ammonia is traditionally produced via the Haber-Bosch process, in which atmospheric nitrogen is combined with hydrogen under high temperatures and pressure. When the hydrogen is sourced from fossil fuels through steam methane reforming (SMR), the process is carbon-intensive, making it a significant contributor to global CO_2 emissions.

However, green ammonia is gaining momentum as a low-carbon alternative, produced using hydrogen from renewable electrolysis and nitrogen from air separation units (ASUs). The adoption of solid oxide electrolysers and the integration of ammonia synthesis with renewable energy sources are expected to improve efficiency and reduce costs over time.

Table 15: Ammonia

Production Method	Hydrogen Source	Energy Requirements	Carbon Footprint
Conventional (Haber-Bosch)	SMR-based hydrogen	High (process heat and SMR)	High (CO_2-intensive)
Green Ammonia	Electrolytic hydrogen (renewables)	High (electrolysis & ASU)	Near-zero (if powered by renewables)
Electrochemical Ammonia Synthesis (Emerging)	Electrochemical hydrogen	Moderate	Low

Applications and Demand Drivers

Ammonia is already an established commodity with significant market demand, particularly in fertilizer production. Beyond its traditional role, green ammonia is emerging as a hydrogen carrier and a maritime fuel, given its ease of liquefaction and transport compared to gaseous hydrogen.

- Fertilizer Production: Ammonia is an essential component in nitrogen-based fertilizers. The transition to green ammonia could significantly decarbonize agricultural supply chains.
- Hydrogen Carrier: Ammonia can be transported globally and cracked back into hydrogen at the point of use, enabling low-carbon hydrogen trade.
- Maritime Fuel: The shipping industry is exploring ammonia as a fuel alternative, given regulatory pressures to reduce greenhouse gas emissions from maritime transport. However, safety and engine adaptation challenges remain.

Methanol (CH_3OH): A Flexible Fuel and Chemical Feedstock

Production Pathways

Methanol is conventionally produced from natural gas via steam methane reforming (SMR), followed by catalytic synthesis. However, green methanol production integrates electrolytic hydrogen with captured CO_2, significantly lowering its carbon footprint.

Table 16: Methanol

Production Method	Hydrogen Source	CO_2 Source	Carbon Footprint
Conventional Methanol	SMR-based hydrogen	Fossil-derived	High
Green Methanol	Electrolytic hydrogen (renewables)	Industrial CO_2 capture / Direct Air Capture (DAC)	Near-zero
Biomass Gasification	Biomass-derived syngas	N/A	Low

Applications and Demand Drivers

Methanol is one of the most widely used industrial chemicals, with applications spanning chemical production, transportation fuels, and maritime shipping.

- Chemical Feedstock: Methanol is used in the production of formaldehyde, acetic acid, and MTBE, making it a key raw material for various industries.
- Fuel Additive & Marine Fuel: Methanol can be blended with gasoline or used as a low-carbon marine fuel, with several shipping companies investing in methanol-powered vessels.
- Hydrogen Carrier: Methanol can be converted into hydrogen via reforming, serving as an alternative transport medium for hydrogen supply chains.

Synthetic Fuels (E-Fuels): Power-to-Liquid (PtL) Solutions for Hard-to-Decarbonize Sectors

Production Pathways

Synthetic fuels, or e-fuels, are produced via the Power-to-Liquid (PtL) process, where renewable hydrogen is combined with captured CO_2 to synthesize hydrocarbons such as synthetic gasoline, diesel, and jet fuel. Fischer-Tropsch synthesis is the dominant technology used in e-fuel production.

Table 17: Synthetic Fuels

Production Method	Feedstocks	Carbon Footprint
Power-to-Liquid (PtL)	Electrolytic hydrogen + Captured CO_2	Near-zero
Biomass-to-Liquid (BtL)	Biomass-derived syngas	Low

Applications and Demand Drivers

- Aviation Fuel: Synthetic jet fuel is gaining traction as a viable drop-in replacement for conventional jet fuel, crucial for decarbonizing aviation.
- Road Transport: Synthetic fuels can be used in existing combustion engines, reducing emissions without requiring new vehicle infrastructure.

Other Hydrogen Derivatives: Emerging Storage and Transport Solutions

Liquid Organic Hydrogen Carriers (LOHCs)

LOHCs enable safe and efficient hydrogen storage and transport by chemically bonding hydrogen to liquid carriers. They offer an alternative to compressed or liquefied hydrogen transport.

Applications: Hydrogen transport, long-duration energy storage.

Formic Acid (HCOOH)

Formic acid serves as a hydrogen storage medium and chemical feedstock, with potential applications in fuel cells and hydrogen delivery systems.

Applications: Hydrogen storage, fuel cells, chemical feedstock.

The Role of Hydrogen Derivatives in Market Development

Hydrogen derivatives play a pivotal role in expanding the hydrogen economy, addressing transport, storage, and application challenges. The transition from fossil-derived to green derivatives depends on technological advancements, policy support, and infrastructure development. Europe’s regulatory initiatives, combined with private-sector innovation, will be crucial in accelerating the adoption of hydrogen-based fuels and chemicals.

Policy Recommendations to Support Derivative Market Development

Targeted Incentives for Production and Use:

To stimulate the production and utilization of green hydrogen derivatives, the implementation of targeted incentive mechanisms is paramount. These incentives should be designed to bridge the cost gap between green derivatives and their fossil-based counterparts, encouraging early adoption and fostering market competitiveness. Tax credits, direct subsidies, and feed-in tariffs are viable options that warrant careful consideration.

1. Tax credits can reduce the upfront capital expenditures for derivative production facilities, enhancing project economics and attracting private investment.
2. Direct subsidies, on the other hand, can provide ongoing operational support, ensuring the long-term viability of green derivative production. Feed-in tariffs, similar

to those employed in the renewable energy sector, can guarantee a fixed price for green derivatives, providing revenue certainty for producers and encouraging long-term investment.

Recognizing the unique challenges associated with each application, sector-specific incentives are essential. For instance, the maritime sector, facing stringent emissions regulations, may benefit from targeted subsidies for green ammonia or methanol production.

A relevant comparator raised during industry consultations was the evolution of the offtake market for sustainable aviation fuel (SAF), which faced similar demand-side constraints in its early development. The SAF sector has benefited from strong policy signals, such as blending mandates and guaranteed offtake frameworks, which reduce revenue uncertainty and support project finance ability. Several stakeholders suggested that the hydrogen market could adopt similar models—including volume mandates or offtake quotas—to establish baseline demand for low-carbon hydrogen in hard-to-abate sectors such as aviation, shipping, and steelmaking. In particular, the use of public procurement or regulatory requirements to create "anchor" offtakers was seen as an effective tool to stimulate early investment, just as it has been in SAF. Participants emphasized that hydrogen market design should learn from SAF's structured path to scale, which combined upstream capital support with legally binding downstream demand instruments.

Infrastructure Development for Derivatives:

The development of robust infrastructure for the transport, storage, and handling of hydrogen derivatives is crucial for enabling a thriving market. This includes investments in port upgrades, pipeline networks, and storage facilities capable of accommodating the specific characteristics of each derivative.

Ports play a pivotal role in facilitating the import, export, and distribution of hydrogen derivatives. Upgrading port infrastructure to handle ammonia, methanol, and other derivatives is essential for supporting international trade and ensuring a reliable supply chain. This includes investments in specialized storage tanks, handling equipment, and safety systems. Pipeline networks are vital for transporting hydrogen derivatives from production sites to end-users. Expanding existing pipeline infrastructure or constructing new dedicated pipelines can significantly reduce transportation costs and enhance supply security.

Public-private partnerships (PPPs) offer a potential and viable financing mechanism for infrastructure projects. Governments can provide seed funding, loan guarantees, or tax incentives to attract private investment in derivative infrastructure. PPPs can leverage the expertise and resources of both the public and private sectors, ensuring efficient and sustainable infrastructure development.

Regulatory Harmonization and Standardization:

The harmonization of standards, certifications, and regulations governing the production and use of hydrogen derivatives across EU member states is critical for creating a level playing field and facilitating cross-border trade. Diverging regulations can create confusion, increase compliance costs, and hinder market integration. The development of common definitions and methodologies for measuring the carbon footprint of derivatives is also essential. Standardized carbon accounting practices can ensure transparency and comparability, enabling consumers and investors to make informed decisions based on verified environmental performance. The EU can play a leading role in developing and promoting these common standards and methodologies, fostering a more transparent and reliable derivative market.

To stimulate demand for hydrogen derivatives, policy mandates and public procurement programs can be effectively leveraged. Mandates for the use of sustainable fuels in aviation and shipping can create a guaranteed market for synthetic fuels and green ammonia, encouraging investment in production capacity.

Public procurement programs can also drive demand for green derivatives by prioritizing their use in government operations. For example, government fleets can be mandated to use vehicles powered by green methanol or synthetic fuels, creating a stable demand base for these products. Public procurement can also be used to support the adoption of green ammonia in fertilizer production for government-supported agricultural programs. These demand-side policies can provide the necessary market signals to attract private investment and accelerate the commercialization of green hydrogen derivatives.

Enhanced R&D Support for Innovative Technologies:

Sustained investment in research and development (R&D) is crucial for driving down the cost and improving the efficiency of derivative production technologies. This includes funding for innovative CO2 capture technologies, advanced electrolysers, and more efficient synthesis processes. Supporting pilot projects and demonstration plants is also essential for validating new technologies and business models. These projects can provide valuable real-world data and insights, accelerating the transition from laboratory research to commercial deployment. Collaborative R&D initiatives, involving universities, research institutions, and industry partners, can foster innovation and knowledge sharing, maximizing the impact of public funding.

Europe can create a supportive ecosystem for the development and deployment of green hydrogen derivatives, unlocking their potential to contribute to a sustainable and decarbonized future. It is imperative that policymakers, industry stakeholders, and financial institutions work collaboratively to enact these recommendations, fostering a robust and thriving hydrogen derivative market that aligns with Europe's ambitious climate goals.

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