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HYRDROGEN AND MARKET "RAMP UP"– PHASES AND TARGET MODELS

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Abstract

This policy brief describes typical ramp-up phases for the hydrogen market. The central thesis is that the goal is to create an established hydrogen market that is self-sustaining and provides business models along the entire value chain. Without early preparation towards this goal, there is a risk of a policy-induced shortage of hydrogen. This, in turn, could call into question the ramp-up itself and its pace. The aim is therefore for the market to ensure a secure and cost-effective supply in the relevant consumer sectors, largely without government intervention.

The market for hydrogen and its derivatives needs to be developed along the entire value chain. The goal of a physically established market, with all its infrastructure and market requirements, can only be achieved by passing through several phases. This applies even more as an internationally linked value chain with various interfaces has to be developed simultaneously.

The construction and regulation of the necessary infrastructure is a crucial factor for the ramp-up of the market. Infrastructure can make a significant contribution to accelerating development. Both construction and regulation require early strategic decisions on the size of the network and the regulatory and commercial conditions of the market that will influence its development.

The different market phases will not be sharply differentiated but will evolve gradually until a level of maturity is reached where a self-sustaining and competitive market is achieved as the target model.

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I. Preparation "Ramp-up"

We commonly talk about the "hydrogen ramp-up". However, this ignores the fundamental challenges that already exist at a structural level.[1]

The development of technology, infrastructure and market conditions along the entire value chain must first be initiated and is subject to considerable uncertainties and risks. This can lead to a wait-and-see attitude on the part of the players and even to the failure of the ramp-up. Only four percent of all announced hydrogen projects worldwide have final investment decisions or are under construction.[2] Considering the dynamic and cyclical development of markets, the hydrogen "ramp-up" should be thought of in terms of at least four phases that characterise market and infrastructure development[3]:

1) the experimental and **development phase**, during which hydrogen and its derivatives are commercialised by pioneers (first movers);
2) the technology and **market ramp-up phase**, in which early followers become active alongside the market pioneers, taking advantage of the experience gained in the early phase. Here, the first procedural patterns and rules of the game will form, but further leaps in invention and innovation will also take place;
3) the **constant market growth**, in which the fastest possible market penetration takes place, as many market shares as possible are developed and the market entry barriers are lowered by well-established processes, structures and market rules;
4) the **established hydrogen market** with first developments towards a commodification of hydrogen and hydrogen derivatives

At the current phase of experimentation and development, actors face significant risks as they operate in a complex environment of systemic uncertainties, ranging from technology to market factors.[4] These uncertainties are exacerbated by the fact that, at all stages along the value chain, the economic viability of projects in competition with established technologies and the reliability of supply can be questioned. Decarbonised and green hydrogen are generally not simple drop-in

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[1] See: Westphal, K. et. al. (2023): Kommerzielle Schnittstellen als Herausforderung für den Aufbau von Wasserstoff-Lieferketten, Policy Brief, H2Global Stiftung. http://files.h2-global.de/H2Global-Stiftung-Policy-Brief-03_2023-DE.pdf.

[2] IEA (2023): Towards hydrogen definitions based on their emissions intensity. Page 7. https://iea.blob.core.windows.net/assets/acc7a642-e42b-4972-8893-2f03bf0bfa03/Towardshydrogendefinitionsbasedontheiremissionsintensity.pdf

[3] Freshfields Bruckhaus Deringer/ Frontier Economics (2023) also argue similarly: H2-Lieferverträge – Strategien für Erzeuger, Händler und Abnehmer in einem unsicheren Marktumfeld, Power Point Presentation 25 January 2023. Slide 15.

[4] See: Westphal, K. et. al. (2023): Kommerzielle Schnittstellen als Herausforderung für den Aufbau von Wasserstoff-Lieferketten, Policy Brief, H2Global Stiftung. http://files.h2-global.de/H2Global-Stiftung-Policy-Brief-03_2023-DE.pdf.

products that can build on conventional supply, logistics and applications. The only exception is the use of grey hydrogen. Given the capital intensity of the developing hydrogen industry, this increases the commercial risks to the point where it becomes unsustainable. It is therefore unlikely that the market will develop in a generic way, with the necessary investment being driven by market forces.

At the current phase of experimentation and development, there are considerable risks for the players, who have to operate in a complex environment of systemic uncertainties, ranging from technology to market factors. These uncertainties are exacerbated by the fact that, at all stages of the value chain, the economic viability of projects competing with established technologies and the reliability of supply are very much in question.

At the same time, considerable market dynamics can be expected, as hydrogen and its derivatives are politically defined as an important pillar of energy and industrial transformation, as well as of mobility (aviation, shipping, and heavy transport), where electrification is not a realistic option. However, the temporal (and spatial) development patterns of value chains and markets are difficult to predict. The technical, commercial, and administrative challenges are enormous. Energy carriers have never had to be introduced in an existing competitive environment and under such time pressure. At the same time, there is considerable political disagreement as to the extent and in which sectors and market segments green and climate-friendly hydrogen and its derivatives should be used. It is therefore not easy to predict which potential applications will receive political support and when. Potential customers are therefore uncertain as to whether, when, in what quantities and in what form they will have access to hydrogen at all.

It seems reasonable that the market will not provide the politically desired allocation. From a (climate) policy perspective, hydrogen and its derivatives should first be applied in energy-intensive sectors that cannot be electrified. These sectors cause high greenhouse gas emissions, but at the same time often face fierce international competition, which severely limits their willingness to pay. Politicians and administrators are therefore confronted with major management and design tasks, which on the one hand concern the accelerated introduction and conversion to hydrogen and its derivatives, a reliable investment and market framework, but also a steering effect and the creation of green lead markets. The development and retrofitting of infrastructure to connect sources and sinks reliably and quickly will play a key role. Ultimately, political decisions will have to determine the shape of the hydrogen market in the early stages, at least as far as the development of market conditions in the "German" market is concerned. With regard to the international supply chains, international coordination will be necessary. From the point of view of the relevant market players, the focus on shaping the political framework also means that they tend to be reluctant to make major investment decisions and wait for the government to define the essential framework conditions. At this early phase, market dynamics are unlikely to develop due to the lack of economic incentives and regulatory uncertainties.

This policy brief argues that an understanding of the ramp-up phases and ultimately a target picture is needed to set the early course for an established hydrogen market. If the course for an established hydrogen market is not set clearly and early, there is a risk of a politically induced shortage of hydrogen. It is doubtful whether key industries can be decarbonised and retained in Germany under conditions of hydrogen shortage, and whether technological leadership in the field of hydrogen production and conversion can be achieved. The market objective is therefore to ensure a secure and cost-efficient supply in the respective consumption sectors, largely without government intervention. The aim must be to create a self-sustaining hydrogen market that ensures not only a secure but also a cost-efficient and thus low-cost supply in the relevant consumption sectors, largely without government intervention.

The lessons learnt from the liberalisation and regulation of the European electricity and gas markets over the last 25 years are not necessarily a blueprint, but they provide an excellent basis for bringing hydrogen and its derivatives to market at an accelerated pace and under competitive conditions.

II. The target model of an established hydrogen market as a guiding principle

For the first time, new energy carriers must be introduced at an accelerated pace and under competitive conditions. In addition, there is a lack of developed logistics and value chains, infrastructure and a significant economic gap compared to competing energies.

Government therefore has an important role to play in defining the climate-neutral and green product, but also in the infrastructure. The key question for regulation is how to achieve an established, self-sustaining market and what characteristics characterise this established hydrogen market. Hereafter, the essential features of such a target model will be described.

The target model is characterised by the establishment of a market for climate-neutral and green hydrogen and its derivatives. Many suppliers and consumers are active on both the supply and demand side, competitive structures have developed, and sustained market liquidity ensures transparent and reliable price signals based on large available volumes from a variety of national, European and non-European sources. Suppliers and demanders manage portfolios that enable temporal and spatial availability and thus sophisticated risk management. The prerequisite for this is a fully functional infrastructure that is integrated into the overall European system and at the same time takes account of Germany's decentralised industrial and consumer structures. Access to the infrastructure is non-discriminatory and standardised for all market participants. Market participants are obliged to use their booked capacities or to offer them to other market participants in the event of changes in demand. Self-sustaining business models have been established, so that in the steady state no financial support is needed through taxation, and the role of the state focuses on compliance with competition rules and the fulfilment of respective product and sustainability standards. In the target model, grey hydrogen is completely phased out and replaced by green hydrogen (and its derivatives); the green product characteristics are traceable and verifiable along the supply chain through reliable certificates of origin.

In order to work towards an established hydrogen market, it is essential that the incentives and risks within the supply chain are distributed between the actors in such a way that the market roles cover the responsibilities to the extent that the risk lies with the actor who can best manage it. This applies to both logistical and commercial risks.

Key framework conditions for an established hydrogen market are:

- Physical availability at any time with developed infrastructure (incl. H_2 storage);
- Access for end users to a wide range of suppliers;
- Variety of importers;
- Regulated non-discriminatory access to the network up to the end customer;
- Supplier competition;
- Sufficient flexibilities (storage);
- Long-term contracts with competitive prices reflecting current market conditions;
- spot supplies, which gradually replace the need for surrogates and back-up alternatives, making them necessary only in rare shortage situations;
- at the import level[5] there may continue to be interest in long-term supplies following market price conditions.

The faster progress can be made along the value chain, the better for the development of the established hydrogen market described above, which will enable an effective and secure supply of climate-neutral and green hydrogen and hydrogen derivatives. The aim of the established hydrogen market is reliable pricing, ideally developed in a larger geographical market where the same conditions prevail. This is to ensure the integrity of the certification chain for confidence in

[5] See: Westphal, K. et. al. (2023): Kommerzielle Schnittstellen als Herausforderung für den Aufbau von Wasserstoff-Lieferketten, Policy Brief, H2Global Stiftung. http://files.h2-global.de/H2Global-Stiftung-Policy-Brief-03_2023-DE.pdf.

the green and climate-neutral product, but also the international connectivity of the certification of hydrogen and its derivatives.[6]

III. Ideal-typical phases on the way to an established competitive hydrogen market

a. Initial situation

The green hydrogen market is currently still at an early stage of development. In addition to the established market for grey hydrogen, a project landscape with numerous pilot plants has emerged in the atmosphere of departure of the last few years. The main characteristics of these projects are the spatial proximity of hydrogen production and consumption, the mostly manageable plant size, and the lack of economic viability. At present, there is no significant hydrogen transport and storage infrastructure, although initial experience is being gained in this area through numerous pilot projects on the technical design of a hydrogen infrastructure. The numerous political and private sector initiatives at global level have created a momentum that, with appropriate preparation, makes relatively rapid development towards the target model appear possible.

However, this will not happen automatically; rather, the development of a green hydrogen economy requires appropriate accompanying measures to further strengthen confidence in the success of the large investments required. In addition to the target model, a basic understanding of the market phases to be passed through is needed, as each of them places different demands on the stakeholders involved. Considering the different global conditions for the development of a green hydrogen economy, it can be assumed that, as with other resources and energy carriers, some regions will be self-sufficient, while others will be dependent on imports from surplus regions.[7] As Europe will become an importing region for green hydrogen in the future, clearly defined development pathways towards a sustainable hydrogen economy need to be identified so that investors in exporting regions can commit to a long-term partnership.

In general, it can be assumed that market development takes place in stages and phases that are structured in terms of time and space. In the following, the individual phases and development paths are outlined in an idealised manner, which means that it is also possible that the phases are

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[6] IEA (2023): Towards hydrogen definitions based on their emissions intensity. https://iea.blob.core.windows.net/assets/acc7a642-e42b-4972-8893-2f03bf0bfa03/Towardshydrogendefinitionsbasedontheiremissionsintensity.pdf

[7] See: World Energy Council (2022): Regional insights into low-carbon hydrogen scale up. https://www.worldenergy.org/assets/downloads/World_Energy_Insights_Working_Paper_Regional_insights_into_low-carbon_hydrogen_scale_up.pdf?v=1680701563.

not passed through in a clearly defined manner and that the transitions can be fluid. As each phase is characterised by its own developmental dynamics, the characteristics listed in the following figure are to be understood as the end points of the respective phase and thus at the same time as the initial state of the following phase.

0. Initial situation	1. Development	2. "Ramp-up"	3. Market growth	4. Established hydrogen market
• Existing market only for grey H_2 • Existing pilot plants for the production of green H_2 • Commercial and political initiatives at the global level • No H_2 transport and storage infrastructure	• Industrial-scale H_2 generation plants at the H_2 hub in Europe or for NH_3 overseas • Regulatory regime for infrastructure existent • Norms & standards for green H_2 defined • Tools for financial support & protection exist • Application: green H_2 is mixed into existing use of grey H_2 • Strategic plan for H_2 infrastructure development and start of implementation	• Regional H_2 application clusters have developed • First international supply relationships are established • Further implementation of the roadmap for H_2 import logistics (ports, ships etc.) • Core elements of an H_2-backbone available • Coordinators take over aggregation function in trade • Long-term commercial relationships • Security of supply through "non-green" backup	• Hydrogen clusters have merged into market areas • Upscaling of international H_2 trade • H_2 import logistics exist • H_2 backbone fully developed • Large-scale connection, also of SMEs • Increasing price transparency, first price indicators emerge • Mixture of short- and long-term supply relationships • Security of supply/ backup largely via H_2 infrastructure (storage)	• Market for green H_2 established (competition on both sides of the market, transparent price signals, sufficient market liquidity etc.) • Fully functional infrastructure available • No need for governmental support • Grey H_2 fully displaced in Germany

*Figure **1**: Phases of market development*

b. Development phase

In order to achieve the goal of climate neutrality by 2045 and the targeted establishment of ten gigawatts of electrolysis capacity in Germany by 2030, the first logistics and supply chains for green and climate-friendly hydrogen and its derivatives to and within Europe and Germany must be established now.

In addition to the climate policy dimension, industrial and technology policy plays a major role. On the one hand, this applies to the goal of becoming a technology pioneer and exporter. In view of the "Inflation Reduction Act", it is the declared goal of the EU Commission to promote a "Green Deal Industrial Plan for the Net-Zero Age", which aims to develop European technologies and secure locations for energy-intensive industries and small and medium-sized enterprises.

The aim of the development phase is to demonstrate the successful implementation of H_2 projects on an industrial scale (projects > 100 MW_{el}). The respective demonstration projects, the testing of process and logistics chains and the commercialisation are to be realised in Europe and worldwide. The aim is to establish value chains and develop business models. Prior to this, the regulatory regime for the infrastructure must be defined so that legally secure investments in H_2 infrastructure projects (especially import plants, pipelines, and storage facilities) can be planned and finalised in parallel with industrial testing. The focus should be on the question of which regulatory framework is best suited to provide the necessary infrastructure as quickly and cost-effectively as possible. The reuse or conversion of existing infrastructures could be an important cornerstone here. The grid has a key role to play: the state must define the conditions for integrated grid development planning[8] (at the level of the long-distance and distribution grids) and the necessary investment conditions. Technically and commercially attractive access conditions for market participants (importers, traders, and consumers) are also crucial. From an exclusively financial point of view, concepts will have to be developed in the early phase, in which the built hydrogen infrastructure can naturally only be partially utilised, which on the one hand allow the networks to be designed for a higher capacity than that of the initial transport volumes and on the other hand do not financially overburden the users of the infra-structure, which will not be utilised to full capacity at the beginning. The market design should therefore allow or at least facilitate the necessary high upfront investments whether for the use of hydrogen or the direct application of ammonia or other derivatives.

The development of clear standards and norms for the green properties of hydrogen and its derivatives is of great importance for the upcoming investments on both the production and the application side. Since Europe will be in global competition with other import regions in the medium and long term, it is crucial to play a leading role in the development and monitoring of standards and to achieve a reasonable balance between its own requirements and those of its competitors.

The development of a hydrogen economy is accompanied by high capital requirements. Due to the high uncertainties that arise especially in the development and ramp-up phase, the avoidance of or hedging against certain risks plays a decisive role in the upcoming investment decisions. In this phase, special challenges arise that can only be solved by government intervention – also in an international context. Particular importance is attached to the establishment of supply, logistics and value chains and the distribution of the associated risks at the interfaces.[9] The H2Global instrument was developed to bridge regulatory risks and reduce contractual risks along the value chain for the early start of first movers.[10] The first tenders with the H2Global Instrument started in December 2022.[11] The instrument, which is based on the Contract for Difference (CfD), opens business models and an experimentation and learning space to test out value creation and

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[8] Integrated network development planning must consider gas, heat, hydrogen and, ideally, electricity. Gas infrastructure can be expanded, converted and decommissioned.

[9] See: Westphal, K. et. al. (2023): Kommerzielle Schnittstellen als Herausforderung für den Aufbau von Wasserstoff-Lieferketten, Policy Brief, H2Global Stiftung. http://files.h2-global.de/H2Global-Stiftung-Policy-Brief-03_2023-DE.pdf.

[10] See: H2Global Stiftung (2022): H2Global – IDEA, INSTRUMENT AND INTENTIONS, Policy Brief. http://files.h2-global.de/H2Global-Stiftung-Policy-Brief-01_2022-EN.pdf

[11] H2Global Stiftung (2022): Hintco went live with the first tender! https://www.h2global-stiftung.com/post/hintco-went-live-with-the-first-tender.

logistics chains. In this early phase, H2Global would like to enable the consortia of companies from the bidding process to make an initial final investment decision. Projects that are scalable on an industrial scale and can be launched in the short term are to be considered. During the implementation of these large-scale projects, the participating companies are provided with learning experiences and experimental space, which increases the likelihood that cost reductions and efficiency gains will take effect in the second expansion stage and in subsequent projects, and that projects will be scaled up significantly. In the ramp-up phase, the tool helps address cost and scaling challenges and serve as a springboard for first movers to launch an initial innovation cycle. As H2Global describes the link of the logistics chain with the landing point in Northwest Europe, the actors involved only need to organise one part of the chain at a time. The instrument thus reduces search and transaction costs and the associated risks in this first phase. It is important to generate confidence in the feasibility of the ramp-up ("success breeds success"). Furthermore, H2Global provides an initial price signal for delivery to a point in the Northwest European market.

At the same time, the first integrated "on-site" projects will develop, and the first point-to-point long-term supply contracts will be concluded. In this context, the desired allocation in certain industries and sectors is crucial for climate policy to contain existing risks. Climate protection contracts will have to play a facilitating role to cushion the additional costs associated with the use of climate-neutral energy carriers and the conversion of industrial processes. Clear signals regarding secure demand and economic viability for investors are crucial.

The current users of grey hydrogen will integrate the first available quantities of green hydrogen into their processes and test which requirements and adjustments a mixed operation will be needed in the upcoming ramp-up phase. This experiential knowledge is the basis for the step-by-step transformation from the grey to the green hydrogen world. In this first phase, the Important Projects of Common European Interest (IPCEI) are to be launched, supporting industrial clusters as well as initial hydrogen network projects and demand-side industrial process conversion projects. These projects provide for the emergence of first hydrogen clusters.

The provision of the necessary volumes cannot be realised without intermediate steps and economies of scale. In order to have the required quantities ready for delivery at an early stage, for example for the steel industry, it is not only necessary to install the plants in Germany and abroad, but also to quickly purchase small, steadily growing quantities in order to build up the logistics chain between producers and customers. Sectors that already use grey hydrogen or its derivatives, such as fertiliser production, the chemical industry and refineries, play a role here. However, the economic viability gap must be bridged here as well. Furthermore, the issue of security of supply must be addressed to have enough available for ramp-up and to be able to substitute in case of supply shortfalls. The use of blue or grey hydrogen should also be envisaged for emergencies.

The central enabler for the development of the market also in this early phase is the development of the necessary import, transport and storage infrastructure for hydrogen or its derivatives. The state has an essential role to play in this phase: a strategic plan for the dimension and implementation of an H_2 network is needed, coupled with regulated access conditions for market players. This is essential not only for the reliability of the commercial constraints, but also for the confidence in ensuring security of supply, which will be the second essential prerequisite for the large conversion investments of (industrial) consumers, besides economic viability. This plan must be at an early stage; its implementation is the key to successful market development in this early phase; it will have to be regularly reviewed and, if necessary, adjusted during the market development phases depending on market successes.

c. „Ramp-up“ phase

The development phase is followed by the ramp-up phase. Important interfaces in the logistics chain of hydrogen and derivates need to be further developed. The necessary technologies have different degrees of maturity and still need to be (further) refined. Electrolysers are scaled up and transferred from individual production to industrial mass production.

In terms of the technologies used and their maturity, the aim is to test technologies, implement robust technology paths and scale up plants. Demonstration projects prepare for series production and commercial operation.[12] It is crucial that a power plant-scale "proof of concept" project finds technical solutions that allow further expansion of production capacity. A stepwise implementation and staggering of the plant size will reduce the realisation risk, allow the learning curve to be followed while maximising the production volume of green hydrogen, and thus have a positive impact on the required funding.

This phase is also crucial when it comes to inventions and innovations. Innovative leaps do not come out of nowhere, but are usually the result of successive innovation steps. In this respect, demonstrators and pilot projects are needed, because the ramp-up of complex technologies and their precise interaction takes time. From research to practical testing, the use of demonstration projects to prepare for series production and regular commercial operation is a crucial step. This is particularly true for the development of maritime areas for offshore electrolysis under the challenging conditions of the Baltic Sea, but especially the North Sea.

The need for investment at all stages of the value chain remains high; the increasing scaling of technologies has improved economic efficiency and thus increased the willingness to invest.

[12] Westphal, K. (2023): Grüner Offshore-Wasserstoff – Viel mehr als nur eine Vision. Tagesspiegel Background. https://background.tagesspiegel.de/energie-klima/gruener-offshore-wasserstoff-viel-mehr-als-nur-vision

Industrial hydrogen clusters and the first import corridors are gradually emerging (also because of the various funding measures).

The detailed further development of H_2 import logistics (ports, ships, storage facilities and pipelines) must also take place in this phase. Of outstanding importance here is the consistent construction and rededication of parallel infrastructures for hydrogen and hydrogen derivatives. The core elements of an "H_2 backbone" for pipeline-based hydrogen transport must be established so that industrial value creation is possible throughout Germany.

Moreover, the development of a storage infrastructure is of central importance. Due to its large underground salt deposits, Germany will play a central role throughout Europe for the storage of hydrogen in salt caverns; geographically, however, these deposits are limited to the mighty salinaries in northern Germany up to the Fulda area.[13] Especially in the market ramp-up phase, buffers are of particular importance, as they provide security of supply close to consumption in times when the continuous supply of hydrogen is not yet established and guaranteed. Here, storage facilities, but also other fallback options, play an important role. During the ramp-up phase, the proposal is more likely to be available in intervals and smaller quantities, while on the demand side, tape deliveries or seasonally fluctuating offtake profiles are needed. Bridging these mismatches will be a major challenge during the ramp-up phase and the transformation of the infrastructures. In this respect, appropriate buffers need to be built up during this phase.

The market ramp-up phase will also be characterised by long-term contractual relationships and a higher degree of economic integration on the supply side. To the extent permitted by energy law, downstream coordinators will often bundle the procurement of hydrogen and its derivatives from upstream coordinators, end-customer supply, long-term booking of (or ownership and operation of) terminal, storage, pipeline, and possibly conversion infrastructure in one hand, in order to be able to offer end-customers hydrogen or derivatives supply as an integrated product tailored to their needs - which ensures consumer confidence in the reliability of supply.

Since the market volume in the development phase is limited, the number of mid/downstream coordinators will also be limited, especially since it makes sense to aim for a certain minimum portfolio size for efficiency reasons (cost degression, portfolio effects). I.e., the mid/downstream coordinators will usually also be aggregators of volumes. However, this may initially mean limited competition among suppliers, as well as intransparency and heterogeneity with regard to the contract prices for ammonia and hydrogen. Considering the pricing of hydrogen in this phase, it is advisable to link the level or the development of the price to existing competitive markets, which

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[13] See: LBEG (2022): Untertage Gasspeicherung in Deutschland. https://www.lbeg.niedersachsen.de/energie_rohstoffe/erdoel_und_erdgas/untertagegasspeicher/publikation_untertageerdgaspeicherung/publikation-zur-untertage-gasspeicherung-in-der-zeitschrift-erdoel-erdgas-kohle-898.html

would not only create confidence in the pricing and the price level but would also be conducive to the competitiveness of hydrogen. Additional confidence in fair market prices can be created by monitoring the market behaviour of (regionally) dominant players by antitrust authorities, as was the case in the energy markets before the liberalisation of the natural gas market.

In the market ramp-up phase, the physical availability of hydrogen is essential. Ultimately, a great deal of responsibility will rest on the last supplier in this phase, who has committed to supply under certain boundary conditions. Like the early phase of the gas industry, there may also be compensatory deliveries between different upstream suppliers in the event of bottlenecks. In addition, security of supply in this phase must also be ensured by other forms of hydrogen (grey or decarbonised hydrogen).

d. Market growth

The transition from “ramp-up” to constant market growth is crucial for the goal of an established hydrogen market and the targeted cost degression. Here, progress will initially be regionally heterogeneous and depend on the number and size of application clusters and infrastructures.

New hydrogen clusters are also emerging in regions that are geographically further away from the import points and domestic production hubs of green hydrogen (and its derivatives). These landlocked island markets will be expanded and successively interconnected in a grid-based and pipeline-free manner. Gradually, the regional application clusters will be merged into market areas.

Due to increasingly more efficient processes, structures and market rules, the barriers to market entry are falling and enable innovation leaps up- and downstream. The resulting increase in market dynamics is leading to ever greater market penetration. Allocation is more and more taking place along profitability criteria and new application areas and market shares are being developed. At the same time, sufficient production and supply must be stimulated and scaled via a reliable demand pull, i.e. the assured demand for green and climate-neutral hydrogen and its derivatives. As a result of this development, hydrogen is opening up further areas of application beyond the major energy-intensive industries such as steel and chemicals. Other sectors such as marine and air transport, heavy-duty transport, and above all energy-intensive small and medium-sized enterprises can increasingly be supplied on a large scale. For the energy transformation and the preservation of value creation in Germany, a clever dovetailing between a supply of energy-intensive small and medium-sized enterprises based largely on green electrons and green molecules and area-wide municipal heating planning is elementary.

The major challenges of a then exponentially growing market for green hydrogen and its derivatives lie in making the distribution of value and risk fair and sustainable over time. This involves defining responsibilities, market roles, liability issues and risk mitigation.

Trading points and delivery zones are successively spatially expanded and linked. Efficient capacity management (terminal, pipeline, storage) can be supported by digital platforms. Logistics chains are becoming established and the H_2 backbone is gradually being fully developed. More and more infrastructural and logistic hubs are emerging. Market area management starts for zones and, parallel to the existing long-term supply relationships, initial bilateral trading ("over the counter", OTC) develops, providing additional price transparency.

For market growth, further networking beyond Germany and its neighbouring countries to the offshore areas is crucial. This requires the construction of gigawatt-scale pipelines to transport large quantities of hydrogen to the mainland and become part of a non-discriminatory hydrogen network. Non-discriminatory access for third parties must already be considered in terms of capacity when planning the starting grid and the H_2 backbone, as well as the storage facilities to avoid bottlenecks in the future.

The continuous and secure supply of green hydrogen and the linkage of the different infrastructures now also allows a security of supply that can largely dispense with grey hydrogen as a backup.

e. The established competitive hydrogen market

The established hydrogen market is evolving out of market growth. The former hydrogen clusters with their expanding supply zones have expanded into contiguous market areas. The H_2 backbone exists at the transmission level as well as important spur lines at the distribution grid level and in the area.

Responsibilities, market roles, and liability issues have been defined, and commercial risk mitigation has been standardised. Business models are established, and the increasing competitiveness of green products and advancing cost efficiency make the government funding instruments of the ramp-up phase superfluous. Physical and logistical hubs are ideally underpinned by virtual trading points, but in any case, they are further developed in regulatory terms to ensure that access to capacities and entry and exit points is as free as possible. Over-the-counter and on-exchange trading is established, as is capacity management via digital platforms.

A liquid trading market, as today's electricity or natural gas market, may establish itself in increasingly mature market conditions with differentiated proposals among many players and clearly regulated infrastructure access; it is not initially necessary for a true competitive market.

For green ammonia, it will be significant to what extent, on the one hand, alternative applications as a fuel (shipping) and as an energy carrier/fuel (e.g. in power plants) play a role in addition to material use in the fertiliser and chemical industries, and, on the other hand, ammonia becomes established as a transport vector for hydrogen. Here, the already mentioned ammonia crackers and nodes, i.e. feed points into an early hydrogen network, play a central role. The established hydrogen market can increasingly develop into a commodification of hydrogen and hydrogen derivatives.

IV. Conclusion

In the European gas market, the history of market liberalisation in the gas industry has shown that competitive market structures can develop after a necessary transition. It is true that the development of a mature market with free access to customers took several decades. In Germany in particular, this was due to regulatory conditions that allowed the market to be demarcated - until 1998. This stage can be significantly shortened by the proposed regulation of infrastructure and the resulting free access to customers and suppliers.

An essential requirement for a fully competitive market is a sufficient supply of hydrogen and its derivatives from many suppliers. This must be accompanied by the early, strategically planned and implemented construction of the necessary infrastructure, which also ensures the confidence of all players along the value chain in the development of the market at an early stage by means of non-discriminatory and cost-effective access. If supply and demand develop as expected, it can be assumed that the market situation described above will gradually develop in Germany and neighbouring EU countries over the next decade. The key challenge is to coordinate the massive investments in terms of content, timing and possibly also location, which will only be possible with the help of state regulation and financial support. The speed of this process depends heavily on the confidence of the players in the value of large investments. This confidence can/must be underpinned by financial guarantees at the beginning, before a self-sustaining dynamic develops.

V. Imprint

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