COMMERCIAL INTERFACES AS A CHALLENGE FOR THE BUILD-UP OF HYDROGEN SUPPLY CHAINS

Policy Brief H2Global Stiftung 03/2023
28. Februar 2023

H2GLOBAL STIFTUNG
Trostbrücke 20457 Hamburg

Authors:
Kirsten Westphal
Hanna Graul
Fynn Hoffmann
Clara Klages
Madjid Kübler
Ludwig Möhring
Jens Völler

ISSN: 2940-8628

The present policy brief was prepared by the H2Global Stiftung on behalf of the German Corporation for International Cooperation (GIZ) and financed by the Federal Ministry for Economic Cooperation and Development (BMZ).

Abstract

The supply chains for green hydrogen and its derivatives are long, complex and intricate, often spanning two or more jurisdictions. The ideal-typical analysis of the green ammonia supply chain shows the enormous challenges that exist in its build-up at all stages of the value chain. The main problems in a highly uncertain market environment include the 1) information problem, the 2) motivation or incentive problem, and the 3) synchrony or parallelism of investments. During the build-up of the structures, commercial risks must be managed at all contractual interfaces. From an organizational point of view, one can assume that the manufacturing, transportation, and further processing steps will not be carried out by new and independent entities in each case. On the contrary, a look at the history of the gas industry suggests that coordination between broader segments of supply, logistics and the value chain will be relevant. The extent to which ammonia is used as a transportation vector and feedstock, and whether it is used for other applications, will ultimately play a role here. There are still considerable residual risks that require government action.

H2Global Stiftung

Table of contents

I. The "ramp-up" challenge

Green hydrogen will have to make a significant contribution to the energy transformation, and the conversion of the industry, transport and mobility sectors on the way to the targeted climate neutrality by 2045 in Germany, or 2050 in Europe.[1] Hydrogen can be stored and can thus make a decisive contribution to the resilience of the energy system. Its generation and use can be designed to serve the grid and the system. The rapid and consistent decarbonization of energy supply and the economy therefore depend not only on direct electrification based on renewable energy, but also on the rapid, scalable, and reliable supply of climate-neutral[2] molecules.[3] For this reason, the rapid build-up of initial supply, logistics and value chains is urgent and a priority.

We commonly speak of the "ramp-up of the hydrogen market / hydrogen ramp-up". However, this ignores the fundamental challenges of the current situation linked to the build-up of supply, logistics and value chains. There are significant technological, economic, and organizational challenges at most stages of the chain. Climate-neutral hydrogen can be transported over longer distances and via different transportation routes such as ship, rail, river routes or roads. Hydrogen derivatives are therefore also hydrogen transport vectors. In the longer term, this also applies to hydrogen imports from countries that are not or cannot be connected by pipelines. At the same time, some transport options[4] are only available in the medium term, either due to technological maturity or due to project planning, conversion, and construction times.

Concerning the build-up of the "hydrogen industry" it is relevant that hydrogen (H_2) can be transported and consumed in the form of derivatives such as ammonia (NH_3), synthetic methane (CH_4), synthetic methanol (CH_3 OH) and Fischer-Tropsch products. Hydrogen itself can be transported both in gaseous form via pipeline, using a carrier such as LOHC, and, prospectively, in liquefied

---

[1] BMWK (2020): The National Hydrogen Strategy. https://www.bmwk.de/Redaktion/EN/Publikationen/Energie/the-national-hydrogen-strategy.pdf?__blob=publicationFile&v=1.

[2] This document will not discuss the "hydrogen rainbow" (National Hydrogen Council (2022): Classification of different paths to hydrogen production ("hydrogen rainbow"). https://www.wasserstoffrat.de/fileadmin/wasserstoffrat/media/Dokumente/EN/2022-04-01_NWR-Information_Paper_Hydrogen_Rainbow.pdf). This analysis focuses on the supply, logistics, and value chain of green hydrogen and its derivatives, as it is a qualitative analysis of the challenges faced by relevant actors along the chain. It should be noted, however, that other technologies can help with scalability and speed of implementation in the transformation phase, for example because they build on specific parts of the supply chain.

[3] National Hydrogen Council (2022): Statement: Russia's war of aggression against Ukraine - Possible impact on hydrogen ramp-up. https://www.wasserstoffrat.de/fileadmin/wasserstoffrat/media/Dokumente/EN/2022-04-01_NWR-Position_Paper_Russias_war_of_agression_against_Ukraina.pdf.

[4] See Staiß, F. et al. (2022): Optionen für den Import grünen Wasserstoffs nach Deutschland bis zum Jahr 2030. Transportwege – Länderbewertung – Realisierungserfordernisse. https://doi.org/10.48669/esys_2022-6.

form.[5] These options – as transport vectors and as application options – differ significantly in terms of technological maturity, efficiency, energy density, cost, and immediate and potential deployment options in the respective sectors. Moreover, the list is not exhausted either. Thus, the complexity is already high due to the very different physical, chemical, and material properties of hydrogen and its derivatives. The possible applications and uses as base material, fuel or energy carrier vary accordingly. Depending on use – in refineries, chemical industry, for high temperature process heat in industry, in fuel cells or power plants – different transport means, and conversion and purification steps are needed that require technologies, processing plants, etc., some of which must first be developed, certified and put into industrial production. In addition, there is considerable uncertainty as to which product chains will be established. It remains to be seen which technological pathway, transport options and utilization paths will prevail and co-exist in different sectors and regions. For instance, this concerns the question whether methanol or ammonia should be used for shipping. The build-up of a “hydrogen industry” should thus be considered with regard to different product chains and the set-up of parallel infrastructures.

Finally, the technology and market ramp-up is subject to considerable uncertainties and risks as well as market dynamics that are difficult to predict. Given the dynamic and cyclical market evolutions, the "hydrogen ramp-up" should be thought of in terms of phases characterizing both market and infrastructure development.[6] The industry is currently in its infancy, i.e., the invention phase, and chains must be built and commercialized by pioneers.[7]

This policy brief analyses the outlined structural issues emerging during technology and market build-up and ramp-up. Analytical starting point is the current situation. We assume that the early phases are essential for a successful and rapid "ramp-up." They are basic prerequisites for scaling, leapfrogging innovation, process change and diffusion of necessary technologies, contractual practices, and business models. Only in this way the market will be able to take shape, grow and become established.

II. The future (physical) supply chain of green ammonia

This paper analyses the ammonia (NH_3) supply chain as a base case. There are several reasons for this: green ammonia is a convertible transport vector, and the maturity level of the technologies

[5] Ibid.

[6] Similarly, Freshfields Bruckhaus Deringer/ Frontier Economics (2023) argue: H2 Supply Contracts - Strategies for Producers, Traders and Buyers in an Uncertain Market Environment, Power Point Presentation January 25, 2023, slide 15.

[7] See: Westphal, K., Möhring, L., Kübler, M. and Völler, J.: Hydrogen and market ramp-up - market phases and target models, Policy Brief, H2Global Foundation 04/2023 (forthcoming).

applied as part of its supply chain is 9.[8] Ammonia is versatile in use – also as a raw material – and can be reconverted into hydrogen (H_2). It has a comparatively high energy density, although cracking for reconversion to hydrogen still requires further development. In this regard, the results of the analysis are largely transferable to other derivatives and hydrogen. Although the issue of the CO_2 source must of course be considered regarding methanol, synthetic methane and Fischer-Tropsch products.

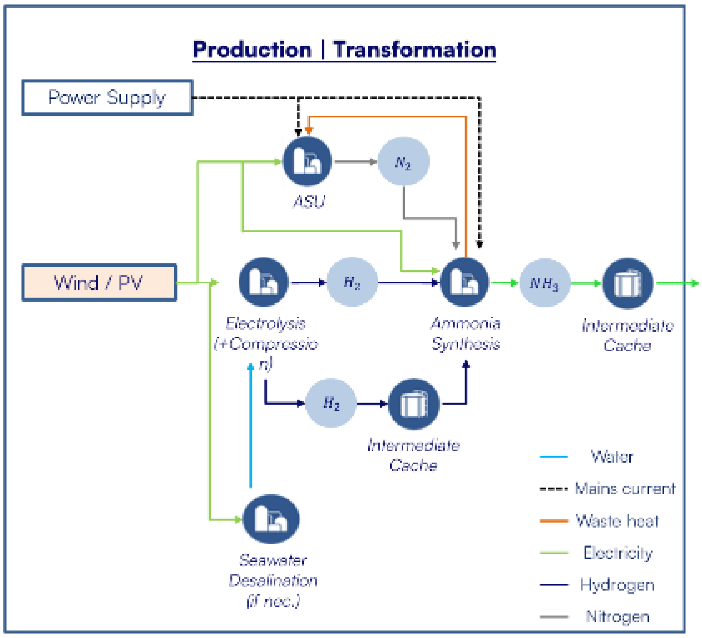

Figure 1: Production and conversion (Figure H2Global; Icons © Energy Systems of the Future (ESYS); Illustrations by Ellery Studio)[9]

The ideal-typical representation outlined here can thus also be applied to other transport vectors and derivatives, as well as to hydrogen itself (see appendix). It includes the generation of electricity from renewable energies, the production of hydrogen and ammonia synthesis (abroad), as well as transport and storage until use, which can take place in different material forms and in different sectors and industries. Figure 1 shows the process of green hydrogen production and subsequent ammonia synthesis.

The first segment is called "Production and Transformation". Of course, the spatial distances between renewable electricity generation, green hydrogen production and subsequent ammonia synthesis may vary. Renewable power generation will occur at a suitable location. Electrolysis

[8] IRENA and AEA (2022): Innovation Outlook: Renewable Ammonia https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/May/IRENA_Innovation_Outlook_Ammonia_2022.pdf.

[9] Staiß et al. (2022): Optionen für den Import grünen Wasserstoffs nach Deutschland bis zum Jahr 2030: Transportwege – Länderbewertungen – Realisierungserfordernisse. https://doi.org/10.48669/esys_2022-6

requires the availability of water (desalination of seawater in some locations). Early in the chain, transportation, both grid and non-grid, may play a role, as synthetic production of ammonia in the Haber-Bosch process does not necessarily have to occur directly at the site of hydrogen production. In this process, ammonia (NH_3) is produced using hydrogen H_2 and nitrogen N_2. Ammonia is liquefied in a condenser at a boiling point of -33°C (1 bar) or around 10 bar (ambient temperature).

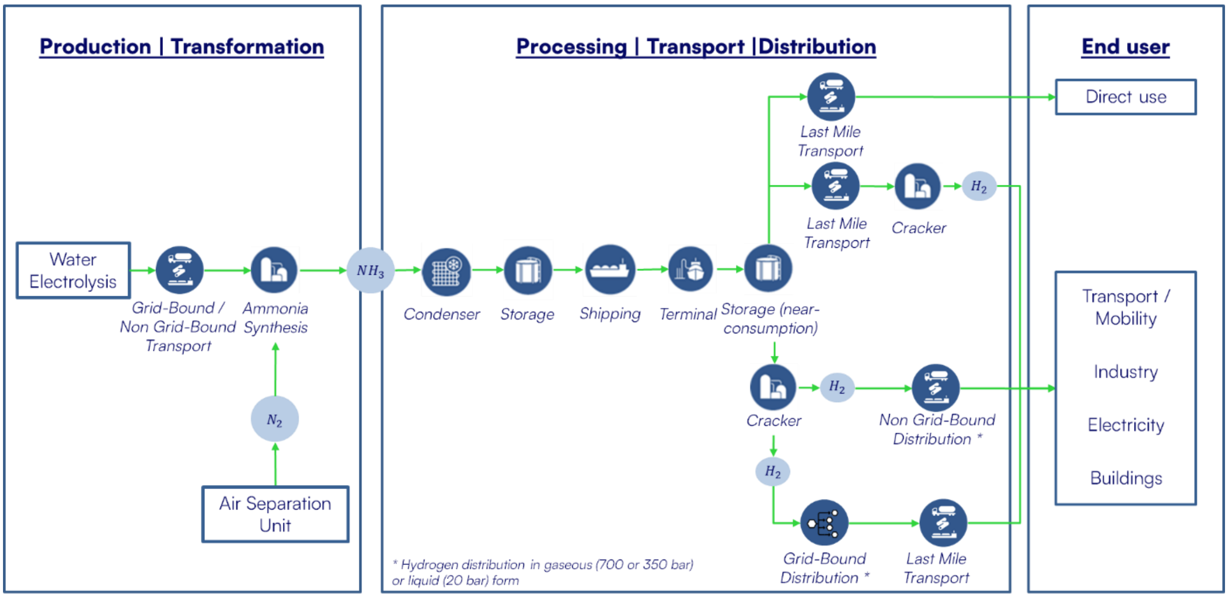

Figure 2: Supply and logistics chain(s) NH_3 / H_2

The "Processing, Transport, Distribution" segment includes different stages. Moreover, routes may differ fundamentally depending on the end user and application, adding to the complexity. The "Production and Transformation" segment is followed by on-site storage and transport to and storage at the port. The import of ammonia is shown here by *Liquefied Petroleum* Gas (LPG) *tanker* as a long-distance transport.

Domestic transport of NH_3 can be done in the following ways: by pipelines such as in the United States, by barge or LPG tanker, tank cars by railway, and tank trucks.[10] Storage facilities as "collection stations" and "buffers" should be considered at several stages of the supply chain. Indeed, the processes taking place at each stage can vary in quantity and frequency for input and output. Production, transport and use or cracking of ammonia and the consumption structures follow different processes and courses of pulse or band strip deliveries. The volumes of supply and demand vary respectively. The downstream stage between (onward) transport and the respective

[10] IRENA and AEA (2022): Innovation Outlook: Renewable Ammonia. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/May/IRENA_Innovation_Outlook_Ammonia_2022.pdf

consumption sector differs depending on the use of ammonia as feedstock or fuel in the form of H_2. Here, the options diverge. Ammonia as both early transport and import option of H_2 is available today. In addition, green ammonia can replace grey ammonia as feedstock to produce fertilizers and other chemicals, for example. This makes it both suitable for testing and scaling up water electrolysis as well as for establishing the first supply chain.

However, two things are important for rapid energy utilization: on the one hand, large-scale crackers for the recovery of H_2 from NH_3 are still under development (technology maturity level 6[11]). On the other hand, the role that new ammonia applications can play and will play, e.g., in the use of power plants or as marine fuel, remains open.

Therefore Figure 2 shows four different routes: at the top, the direct transport and consumption of NH_3 from the port to the end user is represented by trailer, rail, or barge, and theoretically also by pipeline. Here, the storage takes place at the end user.

If ammonia is used as a transport vector for green hydrogen, cracking must take place. This can take place either at the port, at a logistical node for feeding into the hydrogen grid or for off-grid onward transport, as well as at the end customer. The use and local layout of the storage facilities (NH_3 and H_2) also depends on it (see Figure 2). Equally important is the development of logistical hubs where on-grid and off-grid transport routes intersect.

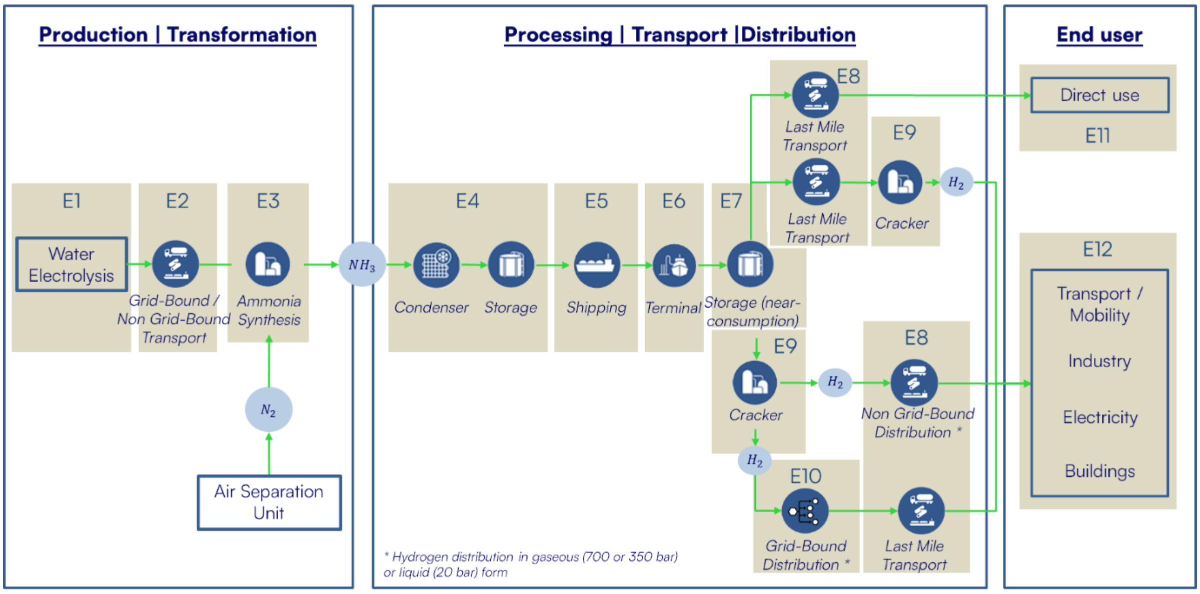

Figure 3: Necessary technical and procedural organizational units

[11] IEA (2022): Global Hydrogen Review 2022. https://www.iea.org/reports/global-hydrogen-review-2022.

E1: Producer of hydrogen
- Owner/operator of renewable electricity production & eletrolyzer
- Located in far abroad country

E2: Transporter (grid/non-grid)
- Owner/operator of transport infrastructure
- Grid: natural monopoly
- Non-grid: competitive market
- Located in far abroad country

E3: Producer of ammonia
- Owner/operator of ammonia synthesis plant
- Located in far abroad country

E4: Operator of export terminal
- Owner/operator of condenser and storage tanks in harbour
- Located in far abroad country

E5: Shipping company
- Owner/operator of ammonia vessels
- Could be located anywhere (HQ)

E6: Operator of import terminal
- Operator of terminal facility
- Located in Northwest Europe

E7: Storage operator
- Operator of storage of liquid ammonia
- Located in Northwest Europe, near-consumption

E8: Transporter (last mile)
- Owner/operator of transport infrastructure (for NH_3 or H_2)
- Grid: natural monopoly
- Non-grid: open to competition

E9: Cracker
- Owner/operator NH_3 cracking plant

E10: Grid-bound H_2 distribution
- Owner/operator of H_2 distribution network
- Natural monopoly

E11: NH_3 direct user
- Industry

E12: H_2 user
- Industry: energy or feedstock
- Mobility, electricity: energy

Figure 4: Entities in the green ammonia supply chain

Figures 3 and 4 illustrate that the technically complex and long supply chain across organizational units requires numerous contractual relationships to display the commercial interfaces.

In summary, the green ammonia supply chain is a very long and complex logistics and value chain involving several production and conversion stages. It is both driven by technology and innovation and requires high upfront investments in generation facilities, infrastructure, and utilization processes. While in conventional oil and gas production, capital costs traditionally decreased from source to sink, here relatively large investment costs are required at almost every stage. Additionally, the supply chain can span and two or more jurisdictions.

III. The establishment of the supply chain and commercial interfaces

a. Challenges

The core elements of the value chain are: Hydrogen production (E1), ammonia synthesis (E3) and ammonia utilization (E11). Regardless of the issue of the place of production and consumption and their connection (transportation), fundamental challenges arise for the actors in these key fields when entering or establishing the ammonia supply chain in the initial build-up phase. The main problems in a highly uncertain market environment include the 1) information problem, the 2) motivation or incentive problem, and the 3) synchrony or parallelism of investments.

Information problem: The actors must know about each other, i.e., know the needs and capabilities of the potential future trading partners, i.e., the other side of the market, and check to what extent their own needs and capabilities match those of the actors on the other side of the market. This is also difficult because the actors usually do not yet exist - especially on the generation side.

Potential ammonia producers or suppliers require demand-related information on, among other things, the required quantity, the temporal consumption profile, lot sizes, requirements for supply reliability, the required product quality, the requirements for proof of the "green attributes" and the willingness to pay of individual consumers. Conversely, ammonia consumers require supply-related information on, among other things, the deliverable quantity, and its development over time (scalability), supply reliability, product quality, and price demands of individual (potential) suppliers.

In the case of global supply chains, the difficulties faced by producers and consumers are magnified. On the one hand, the search field becomes unmanageably large, and on the other hand, the supply chain becomes longer, i.e., production and consumption are spatially far apart and located in different jurisdictions. Since the ammonia has to be transported over long distances, there are also more actors in the transport and distribution field (E2, E4-E10) that have to be included in the supply chain. This increases the number of interfaces in the supply chain, i.e., the supply chain becomes more complex. As shown above, they may necessitate numerous contractual relationships. This results in the difficulty for producers (E1/E3) and consumers (E11) to initiate business relationships in a market environment characterized by high uncertainties. This leads to very high transaction and search costs when initiating ammonia commercialization or procurement. In addition, there are further uncertainties with regard to the infrastructure available in the future, i.e., transport capacities and costs as well as the grid access regime. The risks for investments resulting from the information problem are thus very high.

Motivation and incentive problem. Apart from an abstract understanding and consensus that green hydrogen is needed for successful energy transformation, incentives for investment are lacking. There is currently still an economic viability gap and suitable business models are lacking. Self-sustaining development is prevented by the fact that the maximum willingness to pay on the part of potential green ammonia consumers is generally still lower than the minimum total cost of supplying green ammonia. In addition, the further development of technologies and cost reductions on the one hand offer the prospect of closing the profitability gap, for example through industrial production and scaling. The difference between an investable price from the consumer's point of view and higher total costs of production must be closed. On the other hand, however, there is also the risk of devaluing early investments when innovation and scaling leaps occur. If the specific generation costs of new plants decrease over time, early investments with higher specific generation costs can be devalued by then decreasing specific generation costs. This results in a comprehensive incentive and motivation problem.

Synchronicity problem: In addition, for a larger number of actors wanting to invest in various stages of the value chain, it is crucial to have trust in simultaneous (co)investments by other actors (synchronicity), otherwise one's own investment would be worthless. This leads to each actor waiting for investments from the other actors before making their own investment decisions. As a result, investments then do not occur. This phenomenon is known as the “chicken-and-egg problem”.

b. Commercial risk management

The difficulties described in the previous chapter act in sum as a significant obstacle to the build-up of the value chain. Various countermeasures are available as solutions:

- Product standards and technical norms can make a significant contribution to reduce the information problem. Government regulations or standardization institutes are a basic prerequisite for market build-up, e.g., with regard to product quality or the requirements for proof of “green attributes”.
- Long-term contracts reduce volume-specific transaction and search costs by providing large total supply volumes over the contract term.
- Securing early investments can be solved by a purchase guarantee within the framework of long-term contracts; this does not eliminate the risk, but it can be passed on to customers, at least in part. But here, too, it may turn out that the initial profitability gap can only be bridged by a (time-limited) subsidy, as allowed by contracts for difference, for example.
- The synchronicity of investments along the supply chain can be established through coordination. Traditionally, coordination takes place, for example, via joint ventures or vertical integration forward or backward along the value chain. However, the high costs associated with every stage of the supply chain, coupled with competition law and the unbundling regime in the EU, currently pose a barrier to this, at least in the case of pipeline-based transport. Therefore, the state will also be called upon to promote trust in simultaneous co-investments along the supply chain. In addition, binding contracts (supply contracts or capacity bookings) help to create confidence in synchronous investments.

From a historically informed, but also organizational perspective, it can therefore be assumed that not all production, transport and further processing steps will be carried out by new and independent entities in each case. Rather, a look at the gas industry, but also organizational-structural considerations suggest that coordination will play a role across larger segments of the supply, logistics and value chain (see Figure 4). The purpose of this coordination is to utilize plants, to aggregate volumes, to spread risks, and to build a portfolio (see chapter IV). Here, coordination upstream (production & manufacturing & synthesis) and downstream (further distribution, delivery end customer NH_3 or H_2) is evident. Coordination of individual segments helps to deal with information, motivation, and synchronization problems and to reduce transaction and search costs. Thus, a crucial issue to address is the matter of handover points (cf. Figure 5). It can be either upstream (1) or downstream (2) of transportation. Alternatively, midstream (transport, storage, cracking) coordination can also take place, which can be particularly important for the development of logistic hubs.

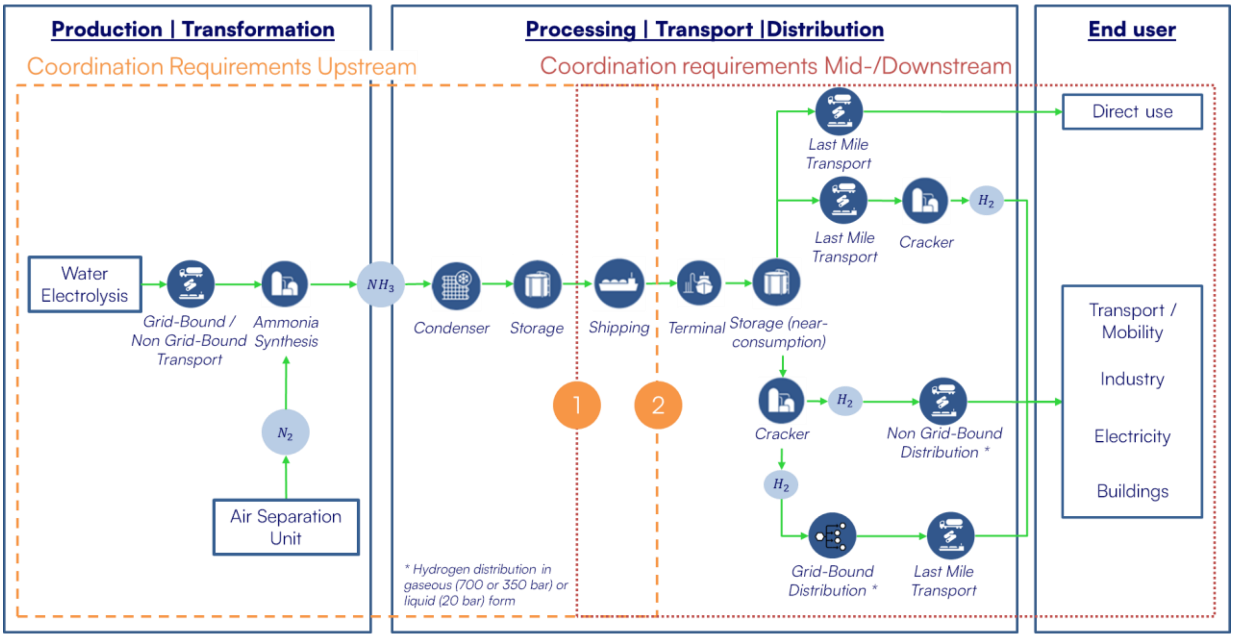

Figure 5: Coordination and transfer points

It stands to reason that coordinating actors, "coordinators," will emerge in places where supply chain investments will be spatially concentrated. In particular, investments will be concentrated in the place or region of green ammonia production, upstream, but also in the place or region of consumption, mid/downstream (see Figure 5 above). After the emergence of an upstream coordinator and a midstream/downstream coordinator, the contractual interfaces may then look like the following:

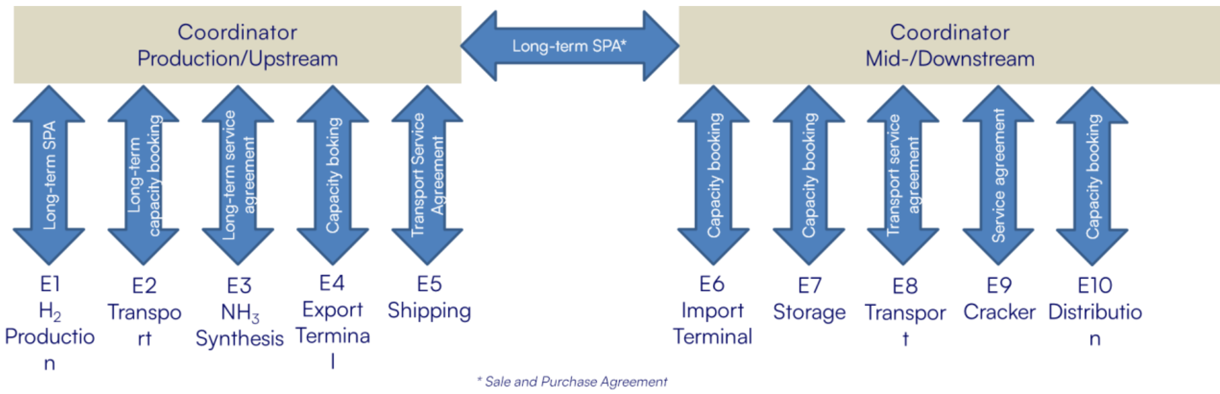

Figure 6: Contractual relationships along the supply chain

Instead of a sequential chain, many parallel interfaces would thus be bundled at the coordinators. The upstream and downstream coordinators would enter a long-term supply contract with each other.

The upstream coordinator would then have contractual relationships with the H_2 producer (E1) for the supply of hydrogen, the transporter between hydrogen production and ammonia synthesis (E2), the ammonia producer (E3), and the export terminal (E4). The marine transport (E5) can be contracted by either the upstream or downstream coordinator, depending on the transfer point in the chain (see Figure 5). In Figure 6 the shipping is contracted by the upstream coordinator.

The mid or downstream coordinator books capacity at the import terminal (E6), at storage facilities (E7), the transport routes (E8), cracking (E9) if necessary, and the distribution network or "last mile" transport (E10) and markets the ammonia or hydrogen to end customers (E11, E12).

Supply contract between upstream and mid/downstream coordinator

The cornerstone in such an organization of the supply chain around coordinators is the supply contract between upstream and mid/downstream coordinators. In this contract, a number of the uncertainties and risks described above can be reduced. The requirements for both sides and possible solutions are summarized in the following diagram.

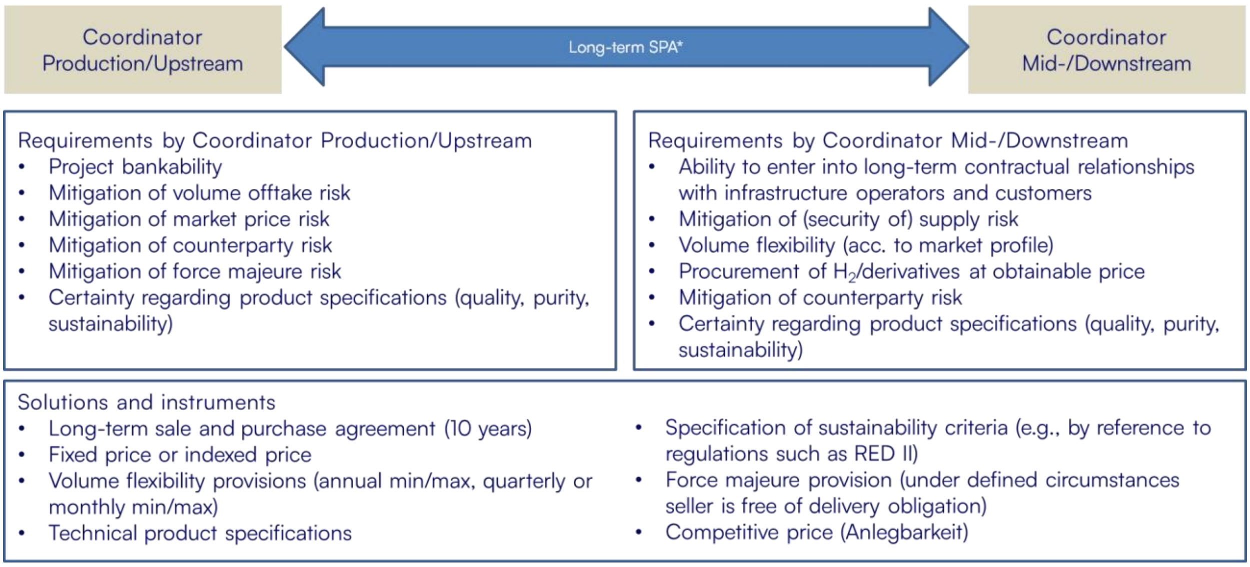

Figure 7: Commercial relationship and risk management

The upstream coordinator must hedge its upstream investments (or those of its contractual partners, esp. E1-E3). This mainly concerns the volume offtake risk and the market price risk. Likewise, the counterparty risk and the "force majeure" risk must be addressed.

The volume risk can be solved by a long contractual term of the supply agreement with minimum purchase quantities. The market price risk can be mitigated by a clear price regulation based on the cost structures of ammonia production and -supply. In practice, however, a compromise will often have to be found between the supplier's requirements (cost recovery) and the buyer's requirements (profitability compared to alternative - green or fossil - energy sources). The counterparty risk cannot always be eliminated but may need to be mitigated through credit checks and collateral or guarantees. A force majeure clause ensures that the upstream coordinator or supplier is released from its delivery obligations in the event of impossibility of delivery for which it is not responsible.

For the downstream coordinator, the challenges during the build-up phase of the supply chain and for concluding contracts depend heavily on the needs and requirements of the end customer. If the end customer already uses ammonia of a different origin ("grey ammonia"), as is the case in fertilizer production, for example, many difficulties are eliminated compared to those end customers who switch from another energy source to ammonia or hydrogen.

Thus, for an existing user of grey ammonia, hardly any investments are required for a switch to green ammonia, and therefore no financing needs or investment risks arise for the end user. This eliminates the problem of synchronicity in terms of investments on the downstream side from the perspective of the upstream coordinator and supplier of green ammonia. Finally, the contracting parties can build on a physically already existing supply chain (ships, warehouses, tank cars, trailers, etc.).

If grey and green ammonia can be used in a mixed operation during a transition phase, the ammonia supply security can be ensured by grey ammonia. Then the green ammonia would be used as a priority, and the grey ammonia would cover the residual demand. Using grey ammonia as a backup solution also eliminates the need for the supply of green ammonia to be controlled over time to meet demand.

Furthermore, there is a pricing framework for green ammonia based on the perspective of the existing users of grey ammonia. The cost of grey ammonia plus the cost of CO_2 emission allowances (or decarbonization of grey ammonia) provides an upper bound on the value of ammonia (chargeable price).

Remaining requirements from the point of view of the mid/downstream coordinator would be with regard to ensuring the product quality (proof of the “green attributes” as well as hedging the counterparty risk and the user-side force majeure risk. In addition, the end user (and therefore the mid/downstream coordinator) needs assurances that they will also receive the green ammonia on a sustained basis in order to meet politically mandated or their own (self-imposed) decarbonization targets. In a rapidly developing and growing ammonia market, a risk for individual end users exists, that suppliers may give preference to other buyers with higher willingness to pay in the new (energy) use areas of ammonia when the supply contract expires.

The latter can be solved by a long contractual term of the supply contract, in which a force majeure clause on the buyer's side should also be included. If the purchaser is unable to take delivery of the ammonia for reasons for which he is not responsible (e.g., in the event of a production stoppage at the end user due to force majeure), he must be released from the obligation to take delivery for the duration of the impossibility. The counterparty risk can be minimized by thorough checks in advance and further reduced by depositing collateral or by third-party guarantees.

Capacity booking contracts between coordinators and infrastructure operators

In order to be able to conclude the long-term ammonia supply contract, the upstream coordinator and the mid/downstream coordinator must simultaneously establish the subsequent contractual relationships. In the case of the mid/downstream coordinator, this entails establishing supply contract(s) with end users as well as contracts with service providers for transportation, storage and, if necessary, cracking. Whereas, in the case of the upstream coordinator, the focus is on the contracts for (or own investments in) the production and supply of green hydrogen as well as ammonia synthesis.

In an overseas supply chain, ship transportation is at the intersection of the areas of responsibility of the coordinators involved and of different jurisdictions. Therefore, the establishment of the infrastructure necessary for ship transportation requires special attention. Significant investments in export terminals, ships and import terminals are required, which must be pre-financed and are associated with utilization risks, especially in the ramp-up phase. The following diagram shows the main requirements from the point of view of the infrastructure operators (in this case, the export/import terminal, or the shipping fleet) and the infrastructure users (i.e., the upstream or the mid/downstream coordinator), as well as possible instruments and solutions to meet the requirements.

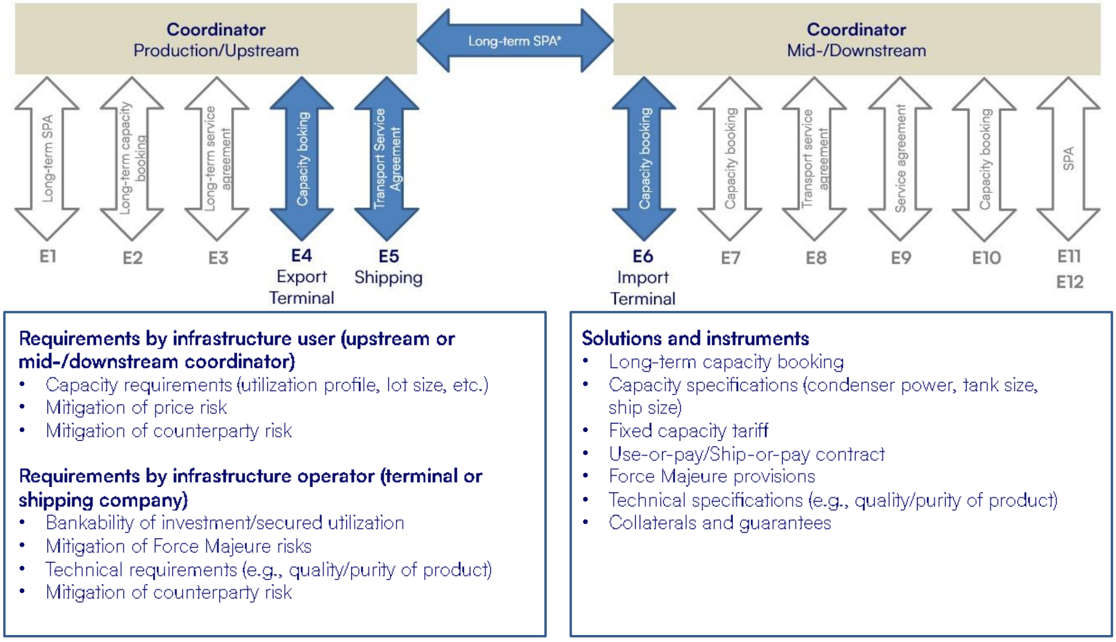

Figure 8: Capacity contracts with infrastructure operators

The upstream and mid/downstream coordinators have a capacity requirement through their supply contract and are therefore able to conclude long-term capacity booking contracts, i.e., to take the utilization risk away from the infrastructure operators. To this end, the capacity booking contract must be structured as a use-or-pay or ship-or-pay contract, i.e., the booked capacity must be paid for regardless of actual usage. At the same time, the capacity charge must be calculated in such a way that it allows full cost recovery over the term; depending on the proportions of CAPEX and OPEX, there can be a fixed (i.e., usage-independent) and a variable (i.e., usage-dependent) charge component.

In addition, the capacity contracts with the infrastructure operators and the supply contract between the upstream and mid/downstream coordinators must be aligned in a number of respects. Delivery volumes and profiles must match the booked capacities. A force majeure event affecting the infrastructure must be recognized and handled as such not only in the capacity contract but also in the supply contract. In addition, the technical quality requirements for ammonia in all capacity contracts must meet the (minimum) requirements specified in the supply contract; this relates, for example, to chemical purity, i.e., there must be no contamination during storage, transport, or processing.

However, upstream, and mid/downstream coordinators cannot resolve all infrastructure-related difficulties in capacity contracts. For example, it is possible that the supply volume specified in the long-term supply contract may be too small to fill an export or import terminal and corresponding vessels of a usual (i.e., economic) size. In that case, infrastructure managers must aggregate demand from multiple users – e.g., through “open seasons” – before investment becomes feasible. Failure to do so jeopardizes not only the construction of the corresponding infrastructure asset, but also the realization of the supply contract and thus the construction of the entire supply chain.

IV. Residual risks and the role of the state

This analysis has addressed the structural issues around the build-up phase of the physical supply chain and its commercial risks. However, given the major challenges of technology and market ramp-up, significant residual risks remain, which require government action. The regulatory framework, i.e., the rules of the game for a hydrogen and hydrogen derivatives market geared towards climate goals, is still largely lacking. Important basic prerequisites for the build-up of a hydrogen market, quasi as *conditiones sine quibus non*, i.e., as necessary but not yet sufficient conditions, are, on the one hand, the rules for the greenhouse gas content and the “green attributes” of hydrogen and hydrogen derivatives. Without a clear definition of the good to be traded in an (emerging) market, there can be no sustainable development of the contracting and trading system and the business models behind it. On the other hand, the pipeline-based transport infrastructure in particular requires special attention due to its characteristic as a “natural monopoly”. The latter is significant in the case that ammonia is converted back into hydrogen and fed into a grid. Here, the integrated planning of a hydrogen network, the implementation, conversion from CH_4 to H_2 and its financing require increased political attention.

Beyond these two basic prerequisites, the technology and market build-up phase pose special challenges for the private-sector contract partners compared with established markets. Security of supply and the distribution of the associated risks at the interfaces are of particular importance. The framework conditions should therefore ideally enable or at least facilitate the necessary capital-intensive upfront investments, whether for the use of hydrogen or the direct application of ammonia. Bilateral contractual risk management by companies is not sufficient to ensure that investments required in the build-up phase are successfully implemented in a timely manner. There are residual risks that already threaten the build-up of the supply chain and require special government attention and coordination. This is especially true with respect to all facilities and transportation modalities, i.e.:

- Green power and electrolyser capacities
- Production/conversion capacities (upstream)
- Infrastructure up to the EU/DE terminal (incl. shipping)
- Unloading infrastructure at the terminal (incl. crackers)

- NH_3 and H_2-infrastructure in Germany: pipeline/storage
- H_2-application technology at the end user.

The risks, which cannot be comprehensively managed by bilateral contracts between the actors, may prevent the necessary investments. They must therefore be supported, encouraged, or promoted by third parties. Beyond supply risks, the main issues here are credit risks and questions of financing capability (bankability).

Special levers are needed to establish a point-to-point supply chain that corresponds to the allocation desired by climate policy in certain industries and that may involve large investments in new processes (e.g., steel industry) on the use or application side. Government intervention, which may need to be coordinated in an international context, can ensure the necessary confidence in the investment decision and the timely completion of the necessary investments along the supply chain. This also applies to credit risks along the value chain; a default by suppliers or service providers due to insolvency must be prevented as far as possible, as supplies cannot be replaced at will during the build-up phase.

V. Conclusions and recommendations

The following conclusions can be drawn from the analysis of the green ammonia supply, logistics and value chain: For kick-starting and then accelerating technology and market ramp-up, the parallel and synchronous establishment of certification and control chains and integrated grid planning are essential. The establishment of a reliable chain of custody is necessary to ensure the integrity of the commodity and the market. At the same time, however, it should stimulate rather than hinder the build-up phase. Integrated grid planning that provides confidence that H_2 or H_2 derivatives will be available in sufficient quantities and in the required form at a given time and place is a prerequisite for addressing the “chicken and egg” problem of matching supply and demand across the various stages.

A significant residual risk in the build-up phase: if the players must assume that the cost of investments along the supply chain will not allow profitable use of hydrogen by the end customer in the long term, this becomes a decisive barrier to investments along the value chain. This risk is real and must be addressed if the necessary upstream/midstream investments are to be made and appropriate contracts signed with importers/aggregators. A hedge of minimum prices for the upstream coordinator must implement minimum price hedging for a period of time. During the build-up phase, the difference between the investable price from the consumer’s point of view and higher total costs of production must be closed by a governmental instrument. To achieve this, solution approaches such as the H2Global instrument can be explored, which in its current design works on the supply and delivery side but can potentially also be applied to the demand side.[12] Furthermore, Carbon Contracts for Difference (CCfD) on the demand side serve to ensure that industrial processes are converted.

For the issue of *security of supply,* it is important in the build-up phase to develop physical back-up solutions that enable end users to use hydrogen (or ammonia) as planned for their processes, even if the contractually promised supply cannot be represented with the green product. Thus, it may be necessary to allow the use of non-green hydrogen or ammonia for secured output on an exceptional basis if sufficient storage capacity for hedging or other green alternatives for it are not available. This option ensures the necessary confidence in the functionality of the supply chain during the build-up phase and thus the willingness to commit to green hydrogen/ammonia applications including the necessary long-term investments.

Regulatory requirements must also allow for the joint processing ("co-processing") and mixing and merging of green and non-green product during transport and storage ("co-mingling"), otherwise the infrastructure costs for the green product would be disproportionately high. To establish a control chain for GHG emissions and "green attributes", a market-friendly mass balancing approach must be introduced, which makes the limits of facilities and infrastructures ("logistical facility") manageable.

With regard to the necessary *infrastructure,* the question arises as to the future role of infrastructure facilities that already exist today for grey ammonia, which are often operated as part of vertically integrated supply structures. Government regulation is necessary both for the use of existing infrastructure and for the development of the infrastructure needed to establish and ramp up the hydrogen market. As shown above, deliveries of green ammonia can build on existing supply chains. However, these are often vertically integrated ownership structures today. At least for the implementation of new storage, transport or cracking facilities, non-discriminatory access for third parties should be considered if these infrastructures are state-supported or incentivized. But then the question arises as to how and under what conditions existing facilities can be opened without discrimination. There is also the question of how to ensure fair competition between the existing infrastructure and new plants built specifically for green ammonia, and how this can be reconciled with subsidies for new plants. The implementation of these infrastructures (including the hydrogen network) is still taking place in a competitive environment, so that joint planning, regulation between existing plants and new investments cannot be approved by collusion for

[12] See: H2Global Foundation (2022): H2Global - Idea, Instrument and Intentions, Policy Brief. http://files.h2-global.de/H2Global-Stiftung-Policy-Brief-01_2022-EN.pdf.

antitrust reasons. Such questions can only be answered by government regulation, making it a matter of political action.

This is particularly relevant for the *pipeline-based transport* of hydrogen. Infrastructures such as grids and storage facilities must be designed to provide free capacities for growing volumes and additional users. A nationwide H_2 grid must be planned and implemented quickly, feasibly and reliably. Companies at both ends of the supply chain must have confidence in the process. At the same time, private entities can build the H_2 infrastructure within the framework of state regulatory requirements and based on integrated infrastructure development plans that need to be defined, providing all players with non-discriminatory access. However, default risks must be covered and stranded assets avoided. The regulatory framework ensures an appropriate return even in the build-up phase, in which the necessary long-term utilization rate is not yet possible. Temporary exemptions from the regulatory regime can also be provided for if they help to accelerate the expansion.

Government regulation is therefore important at various points. Incentive and, if necessary, support instruments for a supply push (as in the case of H2Global) and a demand pull (e.g., in the form of Carbon Contracts for Difference) up to the establishment of green lead markets must be organized.

In summary, especially for infrastructure-bound energy sources, there is a need to establish specific rules to ensure the viability and stability of these markets. In addition to the spatial planning task of establishing transport vectors, nodes and corridors, the supply chains must be technically tested, scaled, and established in such a way that large point-to-point deliveries supply key industries with green NH_3 and H_2. The fundamental goal is to establish rules, i.e., a market design that allows the smoothest possible supply of ammonia or hydrogen at fair prices using international supply chains. For the build-up of international supply, logistics and value chains, government support in the form of strategic partnerships will also be necessary.[13]

During the build-up phase, the market design in Germany will have to consider the fact that only a limited supply of green ammonia or green hydrogen and the necessary infrastructure is available. As noted above, parallel infrastructures and supply chains will also need to be tested and established. Therefore, even a market model that would correspond to the current German natural gas market, for example, is not feasible in the foreseeable future because it lacks all the essential required elements: neither the size of the market, nor the volume, nor the infrastructure, nor the number of suppliers and customers would allow it. Instead, the first step is to respond to

[13] See: Westphal, K, Kübler, M., Möhring, L, Völler J.: Hydrogen and market ramp-up - market phases and target models, Policy Brief (forthcoming).

the current limitations and the resulting security needs of the players. Market design should therefore initially focus on ensuring security of supply, fair prices, and building up the market. In principle, this can be achieved by establishing open market conditions that allow long-term contracts to be concluded.

VI. Annex: Supply, logistics and value chains of H_2 derivatives

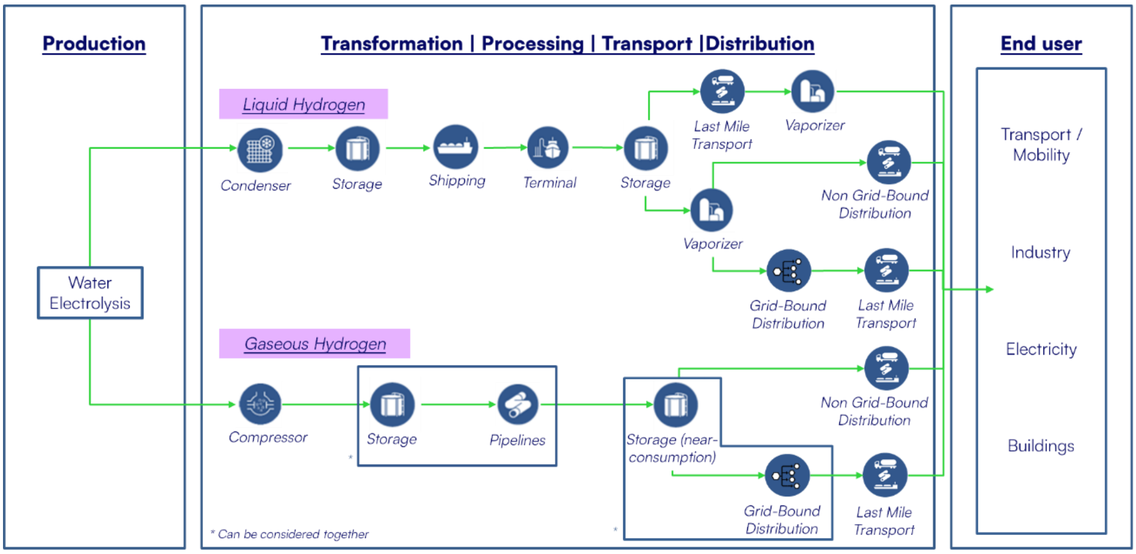

Figure 9: Supply and logistics chain for liquid & gaseous hydrogen

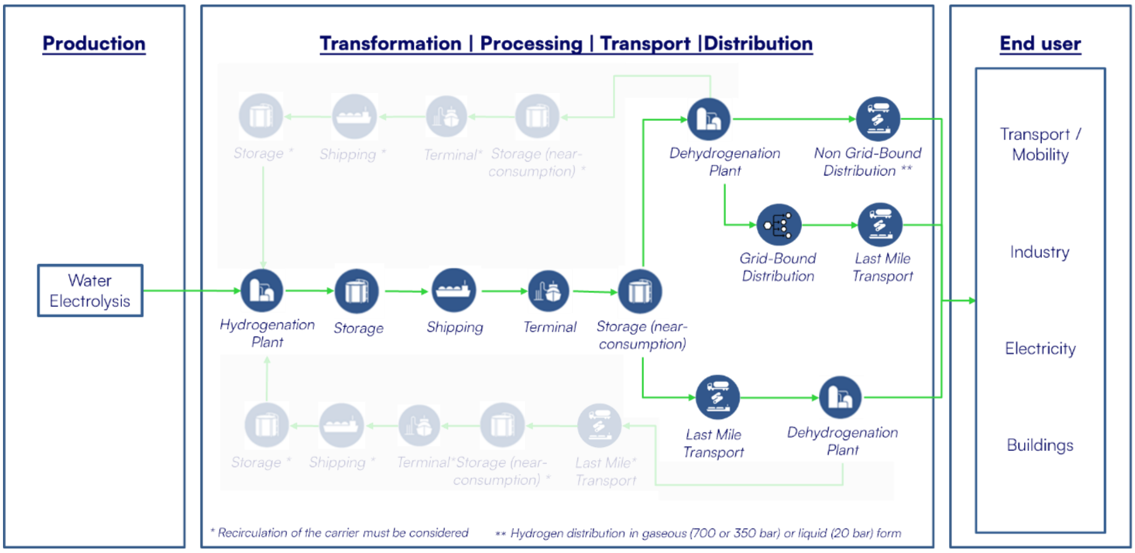

Figure 10: Supply and logistics chain for LOHC

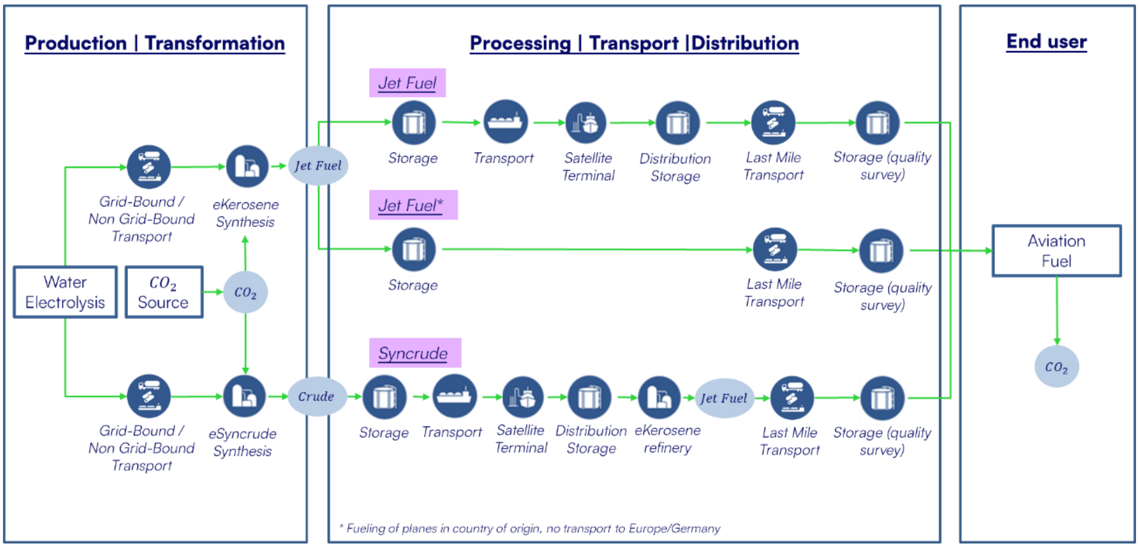

Figure 11: Supply and logistics chain for jet fuel

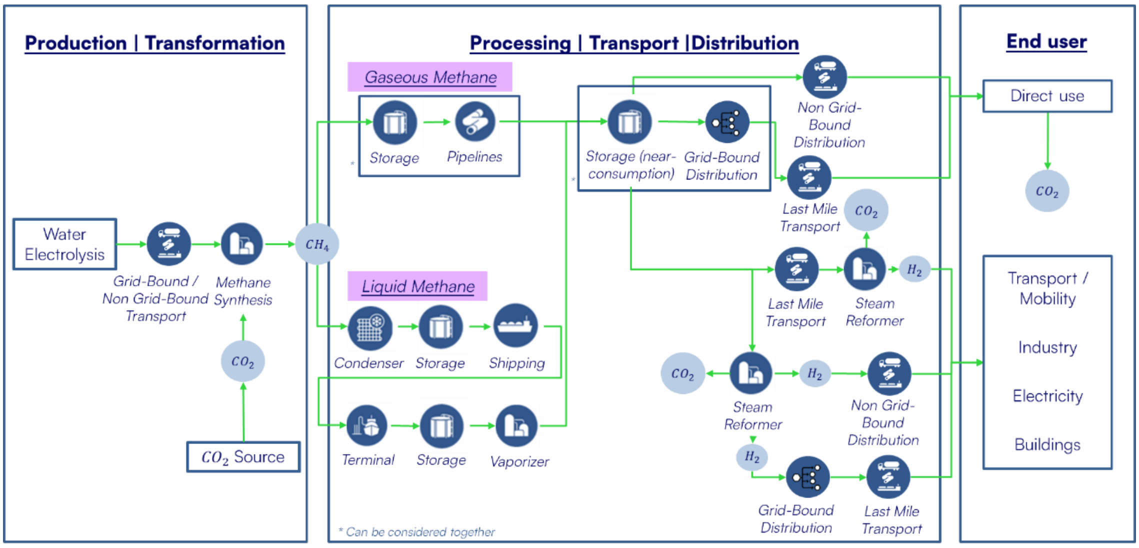

Figure 12: Supply and logistics chain for methane

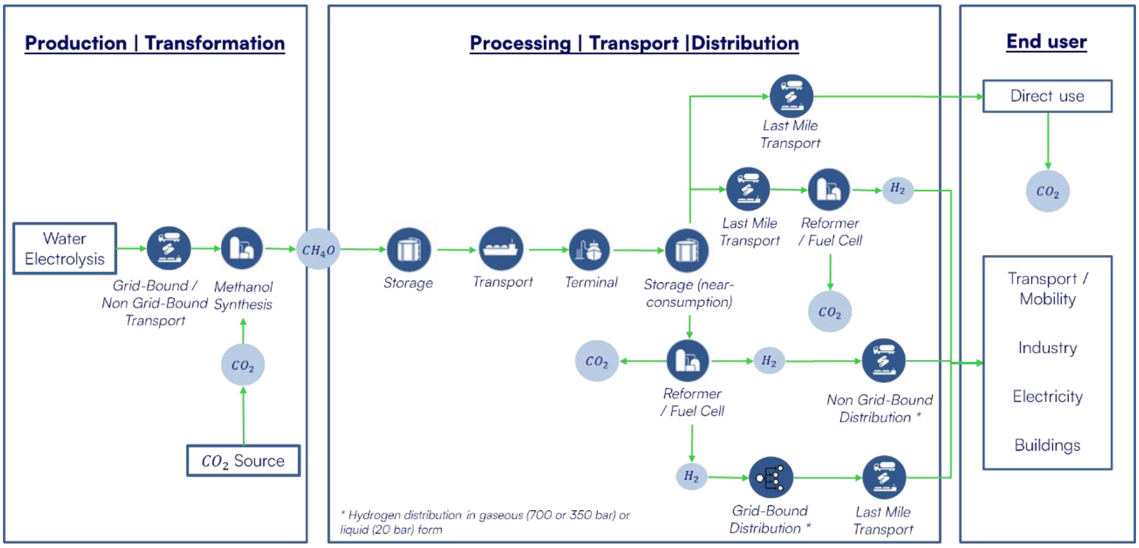

Figure 13: Supply and logistics chain for methanol

VII. Imprint

Publisher:

H2Global Foundation
Department – Analysis and Research
Trostbrücke 1
20457 Hamburg

Authors:

Dr. Kirsten Westphal
H2Global Foundation
Board of Directors/ Executive Director
Trostbrücke 1
20457 Hamburg

Hanna Graul
H2Global Foundation
Trostbrücke 1
20457 Hamburg

Fynn Hoffmann
H2Global Foundation
Trostbrücke 1
20457 Hamburg

Clara Klages
H2Global Foundation
Project Manager
Trostbrücke 1
20457 Hamburg

Madjid Kübler
Team Consult G.P.E. Ltd.
Managing Director
Robert-Koch-Platz 4
10115 Berlin

Dr. Ludwig Möhring
External expert

Jens Völler
Team Consult G.P.E. Ltd.
Authorized signatory
Robert-Koch-Platz 4
10115 Berlin