BEYOND RED III

Decarbonised hydrogen supply strategies in the European industry sector

E-CUBE STRATEGY CONSULTANTS

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Foreword

This white paper was produced by the E-CUBE Strategy Consultants office in Paris, based on desk analyses and interviews conducted with industry players and prospective hydrogen midstreamers in Western Europe in 2023.

Nearly two years after the launch of REPowerEU and as the revised Renewable Energy Directive (REDIII) has just been adopted, this paper looks at which industry sectors are the most prepared to consume decarbonised hydrogen by 2030 and under which conditions.

This paper is based on work carried out by E-CUBE on behalf of its key accounts in the industry and energy sectors on issues related to decarbonised hydrogen production, consumption, and transport.

Issued in 2022, the REPowerEU plan aims at developing ~20Mt p.y of renewable hydrogen consumption by 2030, of which half in industry

i. Demand for decarbonised H2 in industry (inc. refining) is expected to reach ~11Mt p.y by 2030, for energy and feedstocks uses, and half of total supply to come from non-EU imports

ii. REDIII then set out sector-specific targets, opening room for low carbon H2 use in industry but also raising questions about speed and modalities of H2 offtake across sectors

iii. To answer these questions, we interviewed in 2023 representative players of industry sectors expected to consume hydrogen by the end of the decade

Across industry segments, players having already defined decarbonised H2 supply strategies are mostly large consumers of H2 as a feedstock

iv. Most “mature” players are refining, ammonia or steel industry companies faced with no alternative to meet their climate targets than to consume decarbonised H2

v. On the contrary, other (smaller) players tend to be less mature as hydrogen is (seen as) not as a critical feedstock and/or its production not internalised

Yet, even for “mature” players, decarbonised H2 consumption remains conditional and ability to pay for green H2 limited, except in refining

vi. Refining companies are the would-be consumers with the highest willingness to consume renewable H2, with ability to pay at ~5€/kgH2 or more

vii. Other players show no preference for the type of decarbonised H2 beyond the price of decarbonised molecules, and have a lower willingness to pay (<5€/kgH2)

When non-EU imports are considered by 2030, it is most often under the form of derivatives (ammonia) and for direct use under this form

viii. Ammonia consumers are the main type of players willing to consider imports

ix. Other mature players (refiners, steel) can be already part of import projects but targeting only complementary consumption volumes and/or building positions for a post-2030 horizon

Beyond sector disparities, hydrogen supply strategies vary significantly between players and across regions

x. At a player level, strategies differ depending on the company’s level of ambition regarding decarbonisation and the company’s own processes

xi. Importantly, strategies also differ depending on location of players’ production sites and access to competitive local production and/or import infrastructure

Under current conditions, widespread decarbonised H2 offtake in industry beyond large, current consumers of H2 as a feedstock remains uncertain

xii. Beyond refining, willingness to pay for decarbonised H2 is in the low range of expected 2030 LCOH (~3-9€/kgH2), making offtake conditional on the rollout of new regulatory incentives

xiii. Faced with strong uncertainty, would-be consumers should target "low regret" options and define their strategies site by site, considering local opportunities and constraints

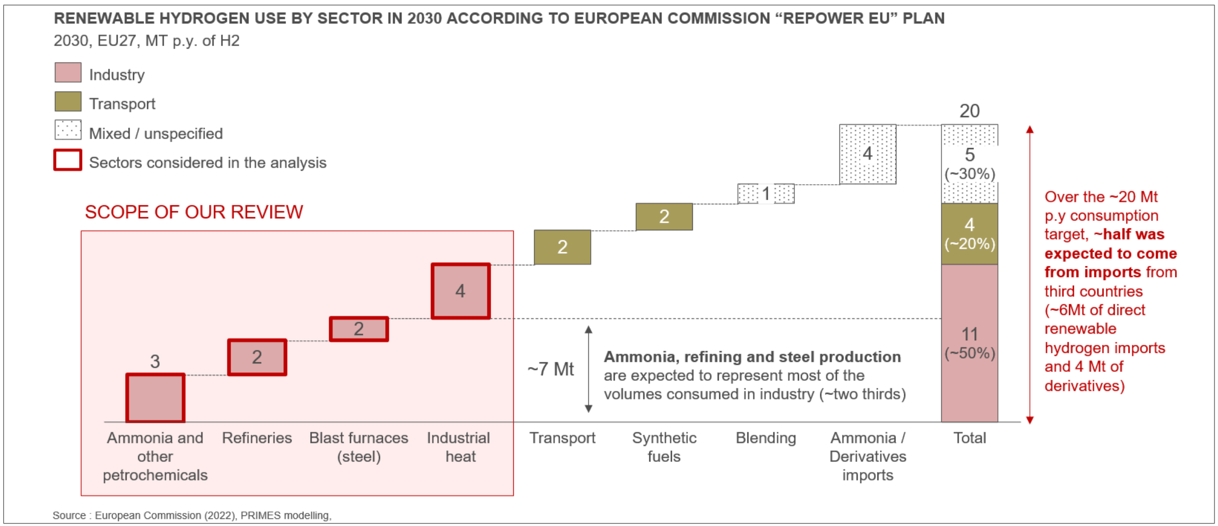
A Issued in 2022, the REPowerEU plan aims at developing ~20Mt p.y of renewable hydrogen consumption by 2030, of which half in industry

Demand for decarbonised hydrogen in the industry sector (including refining) is expected in REPowerEU to reach ~11Mt p.y by 2030, for both energy and feedstocks uses, and half of total supply to come from non-EU imports

Back in 2022, the Commission assumed that hydrogen would be imported from third countries under **a diversity of forms** and would address, within industry, both feedstock and energy uses:

- Within the 10Mt of renewable H2 imports, 60% were assumed to be imported directly under the form of hydrogen from third countries (probably by pipeline), and the rest under the form of derivatives;
- Within the ~11Mt of renewable hydrogen to be consumed in the industry sectors**, ~two-thirds** (7Mt p.y) were to be used **as feedstock** in ammonia, refining, or steel production while one third was to be used as **industrial heat** (4 Mt p.y).

Figure 1 - Hydrogen consumption in 2030 by sector according to REPowerEU



One year later, REDIII was published, opening room for low carbon H2 use in industry but also raising questions about speed and modalities of H2 offtake across sectors

With the now formal adoption of the reviewed Renewable Energy Directive (REDIII), the EU has moved from broad H2 consumption objectives to **mandatory, sector-specific targets** for renewable hydrogen consumption.

- In industry, **42%** of the hydrogen consumed must be **renewable by 2030** and **60% by 2035;**

- In mobility**,** which covers H2 use as a feedstock in the refining process, 1% **of renewable fuels of biological origin** (RFNBO)[1] must be incorporated into the final energy consumption of the transport sector.

Yet, several exemptions to REPowerEU's renewable hydrogen consumption objectives **in industry** have also been introduced:

- A **share of low carbon H2 can be used** to meet the sector's renewable H2 targets**.** In countries where the share of fossil hydrogen in total hydrogen consumption is less than 23% in 2030 (20% in 2035), renewable hydrogen targets may in this way be lowered by 20% - with low carbon hydrogen thus making the difference between fossil and renewable H2 consumption;
- Hydrogen **produced from industrial residual gases and as by product of industrial processes** is not included in the industry hydrogen consumption denominator, basically excluding captive hydrogen production of the refineries, plastics (steam-cracking), and chlor-alkali plants of renewable hydrogen targets.
- Finally, **existing SMR plants equipped with CO2 emission reduction technologies** (such as CCS[2]) allowing to achieve ~70% emission reductions on an annual basis may also, under specific conditions (e.g. Innovation Fund grand awarded) be exempted from the target baseline. This can notably apply to some ammonia production plants.

The sectoral objectives and exemptions defined under RED III raise questions about the **speed and modalities of decarbonised H2 offtake across industrial sectors**. Common uncertainties include:

- Which **industry sectors and players will move first**?
- What will be the **type of hydrogen consumed** (renewable or just low carbon)?
- How **will they secure their supply?**

These uncertainties create **coordination and optimisation issues** between players involved in the H2 value chain: industrial consumers (subject to the new targets), H2 developers (domestic and foreign), H2 midstream players, and public authorities. Indeed:

- **Industrial groups**, faced with short decarbonisation timeframes, must meet the challenge of defining and optimising their H2 supply strategy in a context of an uncertainty around future H2 supply, ability to pass on premiums to consumers, and eligibility to public support.
- **H2 developers and midstreamers** need visibility on demand by H2 type, route, customer segment and on potential support schemes before investing in H2 production, storage and transport assets.
- **Public authorities**, faced with competing demands for public support, need to get a view of both H2 supply and demand to see where imbalances may occur and where public intervention will be the most needed to meet the 2030 targets.

To answer these questions, we interviewed in 2023 representative players of industry sectors expected to consume hydrogen by 2030

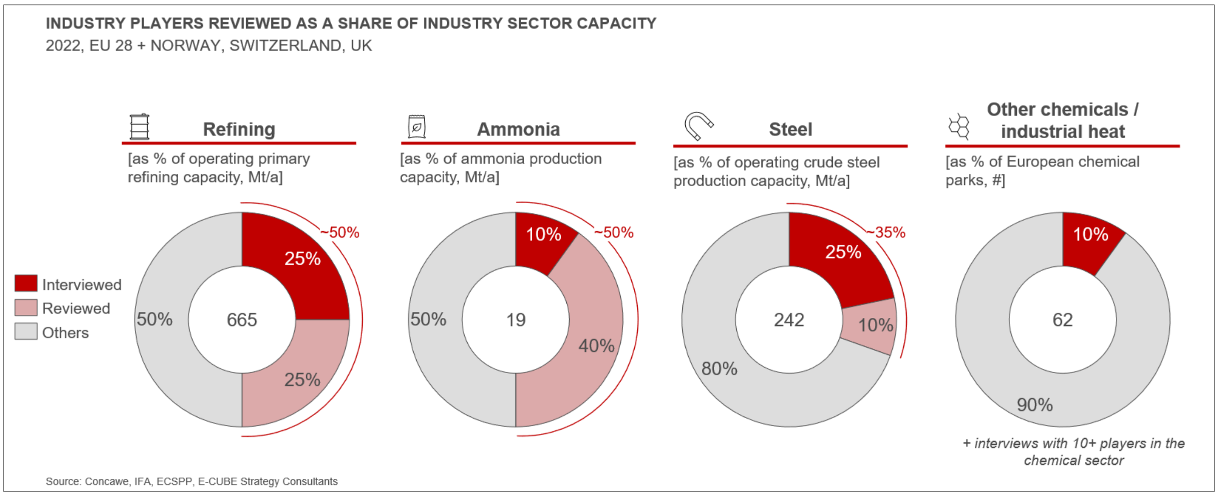
The analyses performed covered four different sectors expected to consume hydrogen for feedstock or energy uses (cf*.* Figure 1)

- Refining;
- Ammonia production (and consumption) for fertilizers;
- Steel production;
- Other chemicals (mainly organic) production for feedstock or industrial heat uses.

[1] Cf. Appendices.
[2] Carbon Capture and Storage.

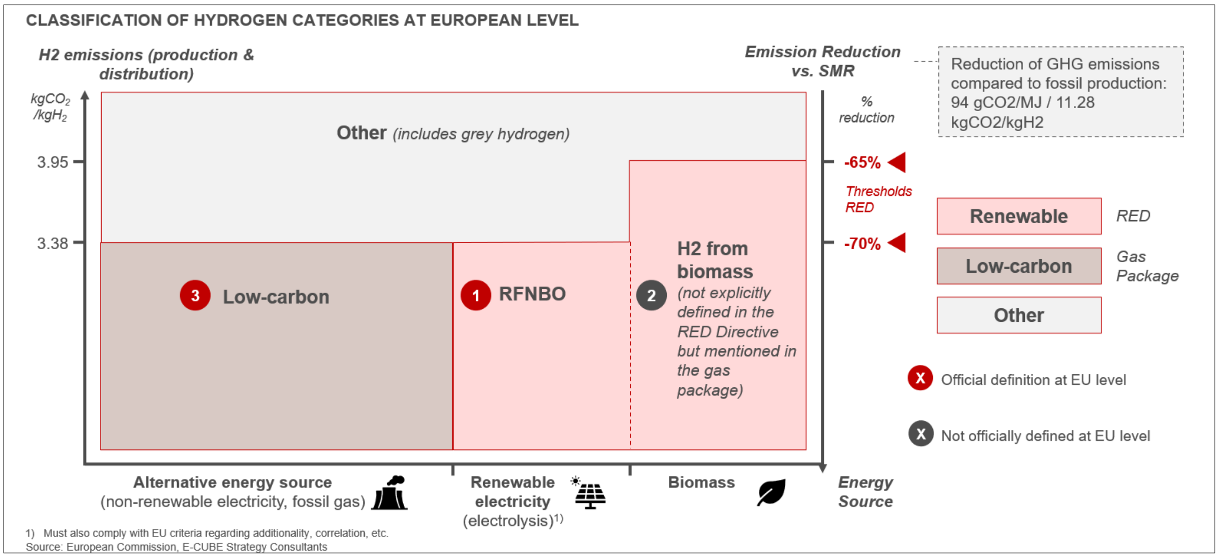
We used a combination of internal and external documentary analysis on the hydrogen procurement strategies of the key players of these industry segments, along with direct interviews with industry companies (for the most concentrated sectors) and chemical parks that host them (for the least, i.e. other chemicals). Indicators of the representativeness of the reviewed players are shown in *Figure* 2.

Figure 2 - Representativeness of contacted players, by sector



For sakes of clarity, we refer in this paper to “renewable hydrogen” for hydrogen produced from renewable electricity sources or biomass abiding by EU’s rules regarding 1) H2 footprint reduction compared to fossil hydrogen as well as 2) additionality and correlation rules regarding renewable electricity supply (cf. ***Figure 3***). We use the term of “low-carbon hydrogen” for hydrogen produced from other sources with at least 70% carbon footprint reduction versus SMR[3]-based hydrogen. Finally, we use the term of “decarbonised hydrogen” for either renewable or low-carbon hydrogen.

Figure 3 - Types of hydrogen



[3] Steam Methane Reforming, the main process used to manufacture hydrogen to date in Europe from natural gas.

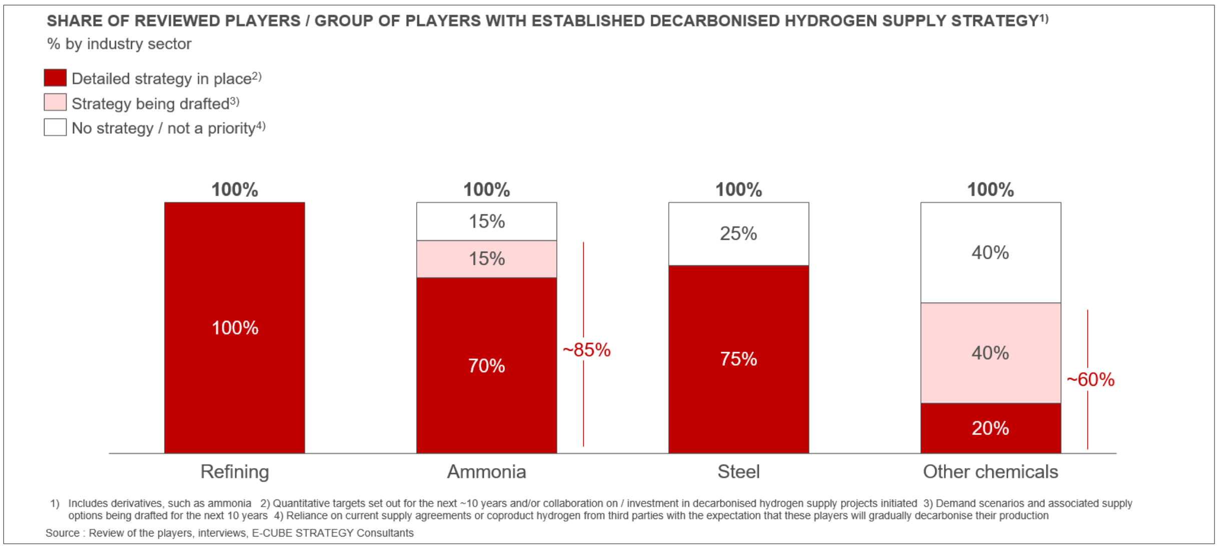
B Across industry segments, the main players having already defined decarbonised H2 supply strategies are large feedstock consumers

Most mature players are refining, ammonia or steel industry companies faced with no alternative to meet their climate targets than to consume decarbonised H2

The maturity of industry players regarding the establishment of a decarbonised H2 supply strategy mostly depends on three factors:

- **absolute levels of hydrogen consumed** (current or expected),
- importance of hydrogen within **overall raw material procurement** (as a share of total costs and carbon footprint)
- access to **own or local coproduction**.

Figure 4 - Players' maturity regarding decarbonised hydrogen supply



In this way, **more than half** of the reviewed players in industry segments which consume or expect to consume **large volumes of hydrogen as a <u>feedstock</u>** (at least ~10 thousand tons of H2 in at least one of their plants as an empirical threshold) and for which hydrogen decarbonisation is a **critical issue to reach their climate targets** (steel industry, fertilizer companies, refiners) have already set out plans to secure decarbonised hydrogen supply by 2030. The higher degree of maturity of these segments is explained by several factors:

- In the refining and ammonia segments, players already **take in charge their own hydrogen supply** and want to integrate or stay vertically integrated over this value chain. They also identify opportunities in investing in (or expanding their) hydrogen production and supply chains for their own consumptions but also that of third parties,
- Being large consumers, most of these players also expect their **demand to exceed potential for local supply** and – in return – their involvement to be critical to build up this supply, therefore incentivising them to adopt early-mover positions.
- Moreover, most of these companies have adopted **2030 decarbonisation targets** that require at **least partial hydrogen decarbonisation** to be reached. Indeed, if in refining, parts of the

hydrogen needs are procured externally and can be considered as included in the company's scope 3 (and the reminder coproduced), this is not the case for ammonia players (often vertically integrated on ammonia production) nor for steel players (decarbonised hydrogen abating direct emissions from their processes).

Most of the players reviewed in these "high maturity" segments are therefore engaged into projects or have concluded cooperation agreements for a supply of decarbonised hydrogen by 2030.

On the contrary, other (smaller) players tend to be less mature as hydrogen is (seen as) not as a critical feedstock and/or its production not internalised

Only ~**20% of other chemicals players** have already defined strategies in terms of hydrogen supply. Several structural factors contribute to these lower levels of maturity:

- Individually, their hydrogen consumption tends to be lower and to represent a smaller **share of overall procurement costs** and company's **carbon footprint**. This leads to milder perception of the risk on hydrogen supply availability as well as a more remote imperative for decarbonisation of their hydrogen procurement.
- Moreover, when located on industrial park (the case of all players we interviewed) their future decarbonised hydrogen supply appears to them even more de-risked that:
  - It is either ensured by a **specialised third-party** (e.g. Air Liquide, Linde …) that has interest in players remaining connected to its network and to – therefore – supply to them decarbonised hydrogen when needed;
  - Or stems for the **coproduction of another player** located nearby (refinery, chlor-alkali plant) – sometimes even from their own processes – which therefore is not subject to the EU's target of renewable H2 use in industry (in its quality of coproduct). This production may also be gradually decarbonised under the supplier's own transition plans.

It is worth noting that, in addition to these structural factors, the impact of the Russia-Ukraine conflict, the ensuing rising gas prices and the partial shutdown of some plants have also contributed to deprioritising the hydrogen decarbonisation topics by creating uncertainty over future levels of activity. These players usually do not expect to launch decarbonised hydrogen projects or procurement before 2030.

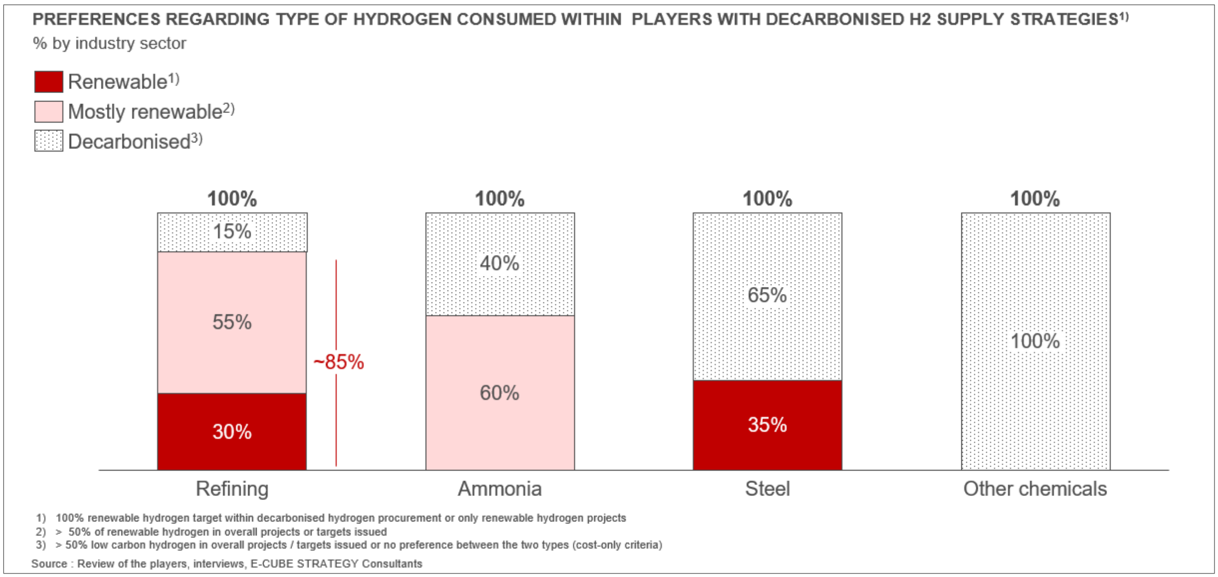
C Yet, even for "mature" players, decarbonised H2 consumption remains conditional and ability to pay for green H2 limited, except in refining

Refining companies are the would-be consumers with the highest willingness to consume renewable H2, with ability to pay at ~5€/kgH2 or more

Players' preferences regarding the type of hydrogen consumed (renewable or "just" low carbon) mostly rests on two factors:

- **Existence of economic incentives:** players which are part of sectors that are regulatorily incentivised to incorporate green molecules in their products (e.g. products consumed in the mobility sector) will place a premium on **renewable** hydrogen procurement, while other players will tend to be more indifferent between low carbon and renewable hydrogen and only consider competitiveness of supply (e.g. organic chemicals, steel).
- **Ability to repurpose cost-effectively** (or to continue using) **existing hydrogen production infrastructure:** players that can easily add CCS[4] on top of their SMRs[5], or ATRs[6] using their industrial flue gases, more easily consider using low-carbon hydrogen rather than renewable hydrogen.

Figure 5 - Preferences regarding type of decarbonised hydrogen



In this regard, **refining** is the industry sector with the **highest willingness to consume renewable hydrogen,** with more than 80% of the reviewed players prioritising renewable hydrogen supply.

- This is mostly due to the existence, in most Western European countries, of **fuel certificates mechanisms** (e.g. TIRUERT in France, GHG-Quota in Germany, HBE in the Netherlands, SICBIOS in Spain) creating a value for renewable hydrogen incorporation in transport fuels –

[4] Carbon Capture and Storage
[5] Steam Methane Reformers
[6] Autothermal Reformers

and therefore, an incentive for refiners to procure renewable hydrogen. Premiums for renewable hydrogen incorporation in these schemes **can reach several euros per kg** (e.g. up to ~6 in France) based on avoided penalties an in part due to the use of regulatorily-defined multipliers for renewable hydrogen.

- Consequently, these players are – for most – **ready to commit for at least part of their supply to procure or self-produce green hydrogen** at prices or costs **equal or above 5€/kgH2 by 2030.**

Other players show no preference for the type of decarbonised H2 beyond the price of decarbonised molecules, and have a lower willingness to pay (<5€/kgH2)

Across mature consumers and beyond the refining industry, **few players commit to a specific volume of decarbonised hydrogen to be consumed at 2030**, and even less on the type of decarbonised hydrogen to be consumed. Most often, a **target range** is defined based on different expectations of decarbonised hydrogen availability and – especially – costs in 2030. Ability to pay premiums in these industries for renewable hydrogen **is lower than in refining (target price < 5€/kgH2)**. Some players can show preferences for renewable hydrogen, purely from a cost-based perspective (expectation of lower or similar costs to decarbonised alternatives).

This is notably the case for fertilizer producers, part of the ammonia industry, which is the **second sector the most willing to consume mostly renewable hydrogen** (~60% of players reviewed), under several forms.

- **Under the form of renewable ammonia imports** for plants located in high LCOE[7] geographies: fertilizer players consume ammonia as a feedstock. Ammonia being more fungible that hydrogen (and millions of tons per year being already shipped), fertilizer players located in unfavourable regions for local renewable H2 production can benefit from **ammonia import from** attractive LCOE geographies (e.g. Middle East, North Africa, Nordics) without supporting at delivery **the cost of ammonia cracking** (~1€/kg). This can make the cost of imported green ammonia as or more competitive than locally produced renewable or low ammonia.
- **Under the form of renewable hydrogen (**to produce green ammonia) for plants based in regions with low LCOE (Spain, Nordics for Fertiberia and Yara) and/or in places with biogas production that can be used to “green” existing SMR facilities’ production at competitive prices (e.g. OCI).

Yet, it must be noted that these players’ **willingness to consume renewable ammonia is strongly conditional** on the absence of more cost-competitive alternatives. In this way, no ammonia consumer rules out using low carbon hydrogen to produce ammonia – which could be for instance achieved by retrofitting existing SMRs with CCS[8]. If a nearby carbon storage is available, this option can allow fertilizer companies to 1) keep operating partially amortized SMR plants, 2) while requiring less CAPEX than fully retrofitting ammonia production plants for electrolytic H2 consumption (SMRs in urea-producing sites being usually already equipped with carbon capture systems for part of the CO2 emitted).

Steel and other chemicals are, among mature players, the industries **the less willing to consume specifically renewable hydrogen**.

[7] Levelized cost of electricity (average net present cost of electricity generation for a generator over its lifetime). Also applicable to hydrogen (in this case designed as LOCH: levelized cost of hydrogen).
[8] Carbon Capture and Storage.

- This reflects, in the case of steel, the constraints of a cost-driven sector, highly exposed to international competition. Propensity to pay for **renewable hydrogen is limited, often below 3€/kg** (without subsidies). The few players intending to consume renewable hydrogen (e.g. Salzgitter) **have made investment conditional** on the granting of state subsidies, whether under the form of direct subsidies (Salzgitter[9]: 1bn€ in funding approved in 2023 from state and federal German government for the first stage of its SALCOS® low-CO2 steel production program) or under the form of H2 production or consumption subsidies (Salzgitter[10]: green steel production will be conditional on how the EEG[11] will develop in Germany).
- In the case of other chemicals, at least in the short run, many players **are not specifically willing to consume renewable hydrogen**, because of a variety of factors: lower levels of maturity, access to coproduced hydrogen, possibility of using industrial flue gas, or - in the case of methanol production - complexity in finding a complementary sources of biogenic or recycled carbon to make renewable feedstocks. In the case of players investigating the use hydrogen for high-temperature heat, expected cost of supply is higher than the premiums they are ready to pay (< 5€/kgH2).

[9] Salzgitter AG, 2023 "*Salzgitter AG receives official notice of government funding for the SALCOS® low-CO2 steel production program*"
[10] Salzgitter AG, 2023 "*Our program SALCOS®*"
[11] *Erneuerbare-Energien-Gesetz*, or Renewable Energy Sources Act. Act which defines (among other) in Germany how the development of renewables is financed, historically by a surcharge levied on electricity consumers, of which electricity for green hydrogen production was exempted in 2023 (Section 69b EEG).

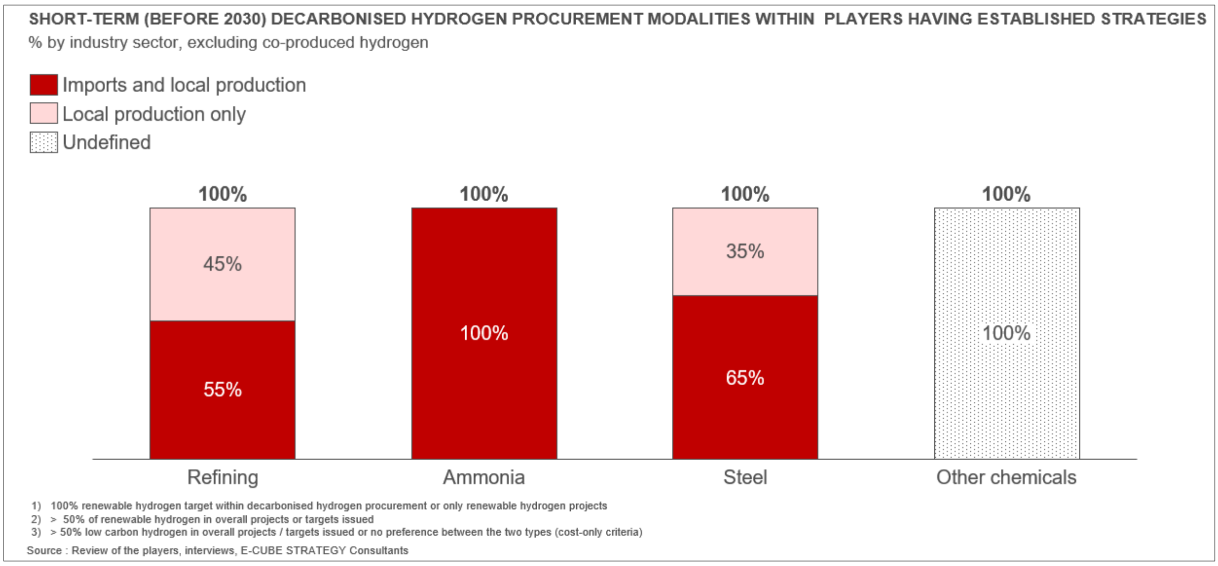
D When non-EU imports are considered by 2030, it is most often under the form of derivatives (ammonia) and for direct use under this form

Ammonia consumers are the main type of players willing to consider imports

Low carbon hydrogen can be produced locally or imported:

- **Local production projects** can be located on-site or immediately next to the consumption site (e.g. on the chemical park). These can be assets operated by the end-consumer or the supply contracted from third-parties;
- **Hydrogen can be imported** from places endowed with most competitive or available resources (e.g. electricity, gas, land) for hydrogen production, located within the consumer's country or not. Hydrogen must then be transported under a gaseous form (through pipelines, or by truck / rail) or under a derivative form such as ammonia to the consumption site. The existence of import or transport infrastructure is then key for this option to be considered.

Figure 6 - Procurement modalities



None of the "mature" players reviewed **plan to rely exclusively on imports**. This reflects their expectations that import and transport infrastructure, at least on many on their sites, will not be available before the end of this decade or may be delayed.

Ammonia industry is the segment the most willing to consider imports, for cost-competitiveness reasons (already mentioned in the previous section) and logistics considerations:

- **Cost-competitiveness**: renewable ammonia imports may be more competitive than local production. Indeed, direct consumption of imported ammonia avoids the costs of cracking (~1€/kgH2 at 2030), while local ammonia projects must add the costs of conversion (Haber-Bosch and air separation unit process) on top of decarbonised hydrogen production (~0,6 – 1€/kgH2 depending on HB[12] unit size).

[12] Haber-Bosch

- **Logistics**: some of the reviewed players are already involved in **ammonia transport** (e.g. Yara already operates for instance more than one dozen of LPG[13] ships, used to carry a few millions of tons of ammonia per year). Moreover, most players benefit – at least on some of their production sites – of ready-to-use ammonia storage and unloading infrastructure.
- **Upside**: most fertilizers players consume ammonia for their own uses but also supply industrial consumers with "merchant" ammonia, offering therefore a potential additional outlet for imported renewable ammonia.

Other mature players (refiners, steel) can be already part of import projects but targeting only complementary consumption volumes and/or building positions for a post-2030 horizon

Refiners and steel industry are the second category of players actively developing **hydrogen import supply chains** (> 50% of the players reviewed considering both local production and imports). The common rationale behind this twin focus on local production and imports is simple: beyond a certain level of consumption (several ~dozen kt of H2 consumption per year) local production potential (at competitive costs) becomes too limited and complementary imports become necessary. Yet, these imports targeting complementary volumes are highly conditional: they may or not be delivered before 2030 depending on whether supply at competitive cost is available.

Beyond the necessity to cover players' self-consumption, developing import value chain also opens opportunities to develop infrastructure that could be mutualised to supply other players. In this way:

- **Refiners** actively develop hydrogen import value chains for their **own uses as well as well as other industries**. BP is for instance studying the development of an ammonia import terminal in Wilhelmshaven (Germany) equipped with a cracker allowing for the delivery of ~130kt per year of decarbonised hydrogen by 2028. In the same way, CEPSA has concluded a cooperation agreement in June 2023 with Yara to develop a maritime supply chain of renewable ammonia from the port of Algeciras (Spain) to Rotterdam (Netherlands) for a volume of up to ~125kt of hydrogen per year[14].
- This is also the case, to a lesser extent, of **some steel industry players**. In this way ArcelorMittal – along players such as Fertiberia, Enagás and DH2 Energy – has formed in 2022 HyDeal España, a hydrogen platform due to produce and transport ~150 kt/year of renewable hydrogen from Spain to France and Germany for its own and other industrial players' uses. If this platform should rely at first (< 2030) on renewable H2 production in Spain from GW-scale electrolysis projects, the ambition is to connect in the medium run (~2030 or later) the infrastructure to North Africa via a subsea pipeline connecting Morocco to Spain (as supported by the launch of the "HyDeal Africa" platform in 2023)[15].

Yet, one should note that **considered imports modalities differ significantly** between refiners and steel industry players. If refiners are involved in the development of maritime hydrogen imports, steel industry players focus nearly exclusively on imports by pipeline. This is mostly due to a lower propensity to pay for decarbonised hydrogen in the steel industry and lower expected cost of renewable H2 delivered by pipeline (cf. Figure 8). This implies also different timeframes: if maritime imports should develop before 2030, uncertainty is greater regarding the development of pipeline-based imports (e.g.

[13] Liquid Petroleum Gas
[14] CEPSA, June 2023, "*Cepsa and Yara Clean Ammonia seal an alliance to connect southern and northern Europe with green hydrogen*"
[15] HyDeal, 2023, "*Spain's Independent Hydrogen Producer, starting 2028*"

the H2Med projects of hydrogen imports by pipelines from Spain to France is planned for 2030 and can be seen as an ambitious timeline).

Comparatively, **other chemical players are less mature.** Their key criterion is to continue to benefit from a secure and pure baseload hydrogen supply at low prices. In that regard, being (or remaining) connected at a hydrogen pipeline appears the most attractive to them, irrespective of whether the hydrogen supplied comes from local electrolysis or ammonia imports and cracking. For uses as feedstock, the use of low carbon hydrogen is considered as an option as long as purity is sufficient for feedstock applications[16].

[16] Usually mentioned as > 99% purity.

E Beyond sector disparities, hydrogen supply strategies vary significantly between players and across regions

At a player level, strategies differ depending on the company's level of ambition regarding decarbonisation and the company's own processes

Players that **decarbonise "first" are more likely to resort to local hydrogen production projects**, most readily available than imports (especially by pipelines). They are also the ones expecting to be able to draw the strongest premiums from early decarbonisation. In the steel industry, Salzgitter is an example of one of these "front-runner" companies, aiming at cutting emissions from its steel production by 95% by 2033, and investing in several local decarbonised hydrogen production projects.

Moreover, within a given industry sector, **processes can differ significantly across players and so too for the considered use of hydrogen**. For instance, in the steel industry, an important distinction is to be drawn between "primary" steel producers (who can be interested by the development of a DRI process) and "secondary' steel manufacturers, which rely on electric arc furnaces and consequently do not need hydrogen as a raw material.

Importantly, strategies also differ depending on location of players' production sites and access to competitive local production and/or import infrastructure

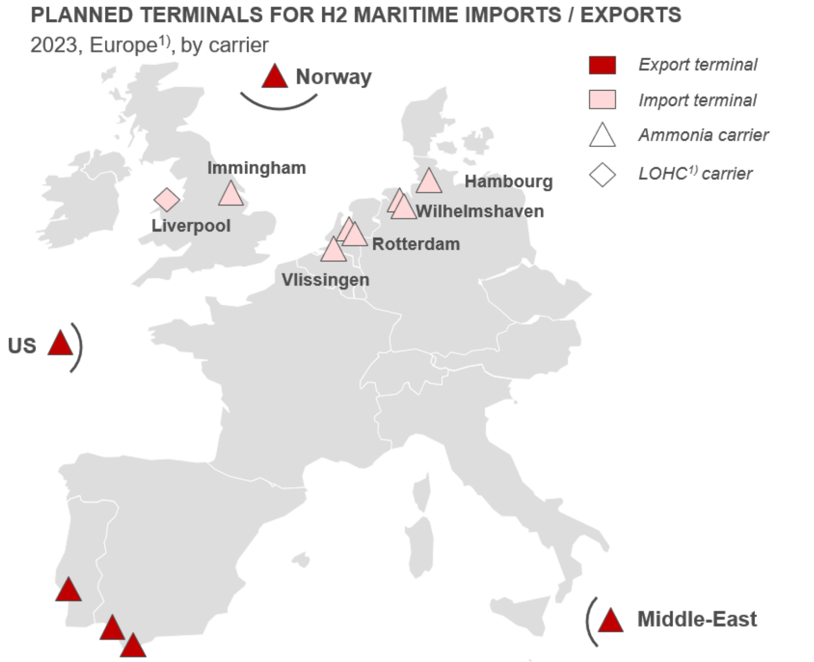
In Southern Europe and Nordic countries, regions endowed with low renewable LCOEs industrial sites will tend to resort more to **local hydrogen production** and consume renewable hydrogen. Imports by pipeline can be considered for sites located in Spain from North Africa, but seldom before 2030.

In the **ARA[17] and northern Germany regions, maritime hydrogen imports tend to be considered along local hydrogen production**. Indeed, maritime imports are dependent on the existence or development of related infrastructure. This zone is where most ammonia import terminals are being developed in Europe along with ammonia crackers, many planned to be commissioned before 2030 (cf. Figure 7). Downstream of this infrastructure, Netherlands have started building or converting part of its natural gas transport infrastructure to hydrogen, with the aim of linking the five major industry clusters in Netherlands[18] and with interconnections planned with Germany and Belgium by 2030. Many of the players interviewed, especially when maturity is limited, expect to rely on this infrastructure. Specifically, **the port of Rotterdam is expected to play a leading role** as a hydrogen/ammonia/methanol import hub, being already the leading port in the North Sea regarding liquid bulk goods[19] imports (nearly ~50% market share in 2020 over total liquid bulk throughput in Hamburg-Le Havre ports region).[20]

Finally, the options considered also depend on whether local **hydrogen coproduction is available.** In some of the interviewed chemical parks in Germany, coproduct hydrogen valorisation is a key contributor to feedstock decarbonisation – although almost never sufficient to cover entirely the needs that would entail a full decarbonisation of existing hydrogen consumption.

[17] Amsterdam / Rotterdam / Antwerp.
[18] Around Antwerp, Amsterdam, Rotterdam, Ghent, Groningen/
[19] Crude oil, mineral oil products, LNG, other liquid bulk
[20] Port of Rotterdam, 2021, "Facts and figures"

Figure 7 - H2 terminalling infrastructure under development



1) Non-exhaustive listing of export geographies. Existing NH3 terminals not represented, unless part of an expansion plan
2) LOHC : Liquid Organic Hydrogen Carrier
Sources: review of the players, Ammonia Energy Association, E-CUBE Strategy Consultants

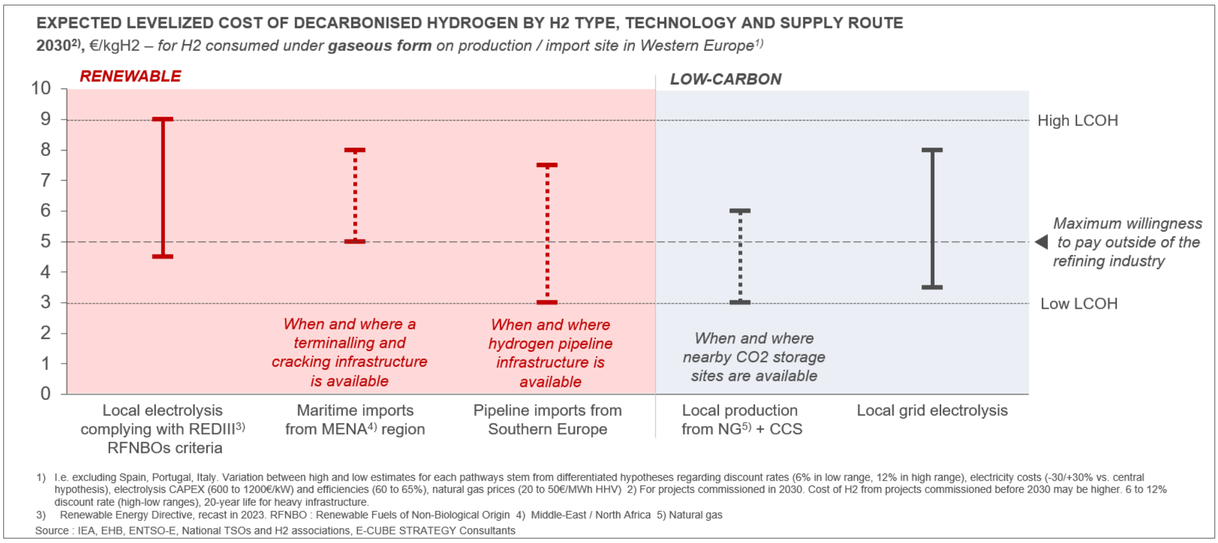
F Under current conditions, widespread decarbonised H2 offtake in industry beyond large, current consumers of H2 as a feedstock remains uncertain

Beyond refining, willingness to pay for decarbonised H2 is in the low range of expected 2030 LCOH (~3-9€/kgH2), making offtake conditional on the rollout of new regulatory incentives

As mentioned in section C (p. 10), willingness to pay for renewable hydrogen for all "mature" players reviewed **is below 5€/kgH2** except in refining. Without regulatory schemes giving an additional value to renewable hydrogen versus low carbon hydrogen in other industry sectors, this ~5€/kgH2 threshold also describes the maximum willingness to pay for decarbonised hydrogen of ammonia, steel and other chemical players.

Non-refinery players' willingness to pay **falls in the lower range of expected LCOH for decarbonised hydrogen for projects commissioned in 2030** (cf. Figure 8Figure 8)[21]. The lower values of the ranges shown below are based on a combination of **favourable assumptions** regarding electricity costs, strong electrolysis CAPEX reduction (to ~600€/kW in 2030 vs ~1500-2000€/kW currently), electrolysis efficiency and discount rate, as well as – for SMR + CCS pathways – low natural gas prices (around ~20€/MWh HHV). This suggest that, unless these favourable factors are combined, decarbonised hydrogen consumption by 2030 may be limited to the refining sector and potentially a handful of large ammonia and/or steel players supported by state or EU subsidies.

Figure 8 - Levelized costs of decarbonised H2 (under gaseous form) delivered in Western Europe



If REPowerEU's ambitions are to be met and hydrogen more widely used in industry, this may require the rollout of wider regulatory schemes to **either raise industry consumers' willingness to pay** (e.g. by replicating schemes such as renewable fuel quotas in the transport sector, by the implementation of

[21] LCOH for maritime imports represented on Figure 8 includes the cost of cracking (~1€/kgH2). For consumers consuming directly hydrogen under the form of a derivative (ammonia), this cost is avoided, and maritime imports become one of the most competitive renewable option.

the CBAM[22] to advantage low carbon steel and ammonia production) and/or to **lower the cost of decarbonised hydrogen passed on to industry** (e.g., as in the Salzgitter case, by direct state subsidies, electricity taxes or levies exemptions, …).

Faced with strong uncertainty, would-be consumers should target "low regret" options and define their strategies site by site, considering local opportunities and constraints

Would-be hydrogen consumers are currently faced with **two types of uncertainties** impacting both the value they can expect from renewable hydrogen offtake and the cost / supply options associated to it.

- **Regulatory uncertainties**: if a range of policy instruments is set to enter into force that may give **a value to renewable hydrogen**, their details are yet to be fleshed out. In this way, if the CBAM should be operational before 2030 (permanent system to enter into force in January 2026), its efficiency in promoting local decarbonised production of key feedstocks is yet to be demonstrated. Moreover, if RED III renewable hydrogen quotas in industry should be transposed into national frameworks by 2030 under the form of incentives or penalty schemes, the shape that will take these schemes and their coverage has yet to be defined.
- **Techno-economic uncertainties:**
  - Regarding **expected LCOH for renewable hydrogen in 2030:** this latter depend on multiple parameters, including renewable production costs or electrolysers CAPEX, both variables which evolution have been demonstrated in the past years to be hard to predict. Regarding electrolysers CAPEX for instance, the IEA has strongly revised upwards between 2020 and 2023 its estimates for current electrolyser CAPEX (from about ~1000€/kW in 2020 to ~1500- 2000€/kW currently)[23]
  - Regarding the **development** and **timing of development** of import and transport infrastructure, conditioning the access to maritime imports or to pipeline supply – an essential criterion to ensure security of supply for players without backup options such as proprietary or contracted SMRs.

Considering with this double uncertainty as well as the importance of players' processes, business models and geographical context as mentioned in section E (p. 15), companies looking to define a decarbonised hydrogen supply strategy should necessarily:

- Assess the **criticality of H2 supply decarbonisation**, which depends (mostly) on the existence of alternative decarbonisation options, the hydrogen volumes to be consumed or decarbonised, their share in the company's feedstocks or energy costs, and in its overall carbon footprint;
- If hydrogen supply decarbonisation is critical, define the company's **willingness to pay** for decarbonised hydrogen (i.e. demand curves) based on its ability to **pass on decarbonisation premiums** to consumers under different assumptions (ability to pass on premiums being dependent on the development of regulatory schemes such as the CBAM, the type of hydrogen procured, but also on the company's positioning and business model);
- Then, assess **site by site** what are the different **available decarbonised hydrogen supply options** and assess **their competitiveness** (i.e. draw supply curves) under different technical and economic assumptions,

[22] Carbon Border Adjustment Mechanism
[23] IEA publications on Hydrogen from 2020 to 2023 *("Global Hydrogen Review"*, "*The Future of Hydrogen*", "*Green hydrogen policies and technology costs*").

- Based on the comparison between willingness to pay and competitiveness of supply sources under different scenarios, **identify "low regret" options** (defined as supply sources with LCOH below minimum willingness to pay in most probable scenarios).

These questions can be addressed at a company level or **at the level of industrial parks** in which the company is located, as the presence of import, storage and transport infrastructure (assets which development require visibility over the consumption of the whole industrial park) conditions which hydrogen supply pathways are feasible and attractive.

In this regard, E-CUBE has built a comprehensive expertise in terms of:

- **Players' coordination around the definition of shared hydrogen roadmaps** – for instance in the context of decarbonisation projects for leading industrial zones in France;
- Definition of **individual companies' hydrogen strategies** (whether it be consumers, producers, or infrastructure players) all along the hydrogen value chain.
- Definition of **hydrogen supply and demand scenarios** (cf. Figure 9) in context of high technical, economic and regulatory uncertainties to objectivize "low regret" options for hydrogen customers and **optimize corresponding hydrogen infrastructure** (cf. Figure 10).

Figure 9 - Definition of hydrogen demand scenarios for an industrial park

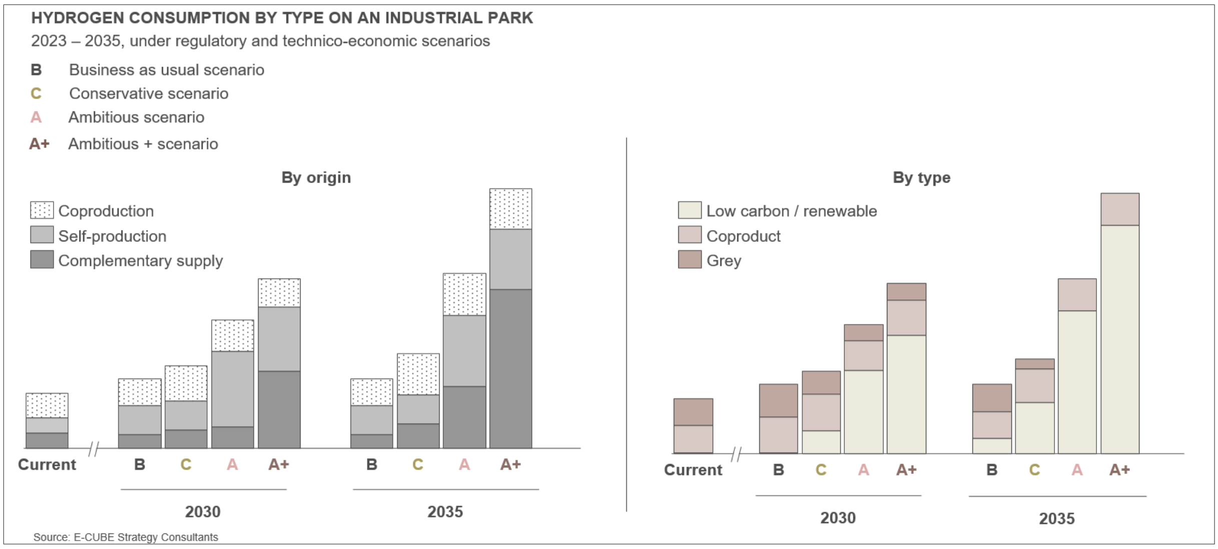
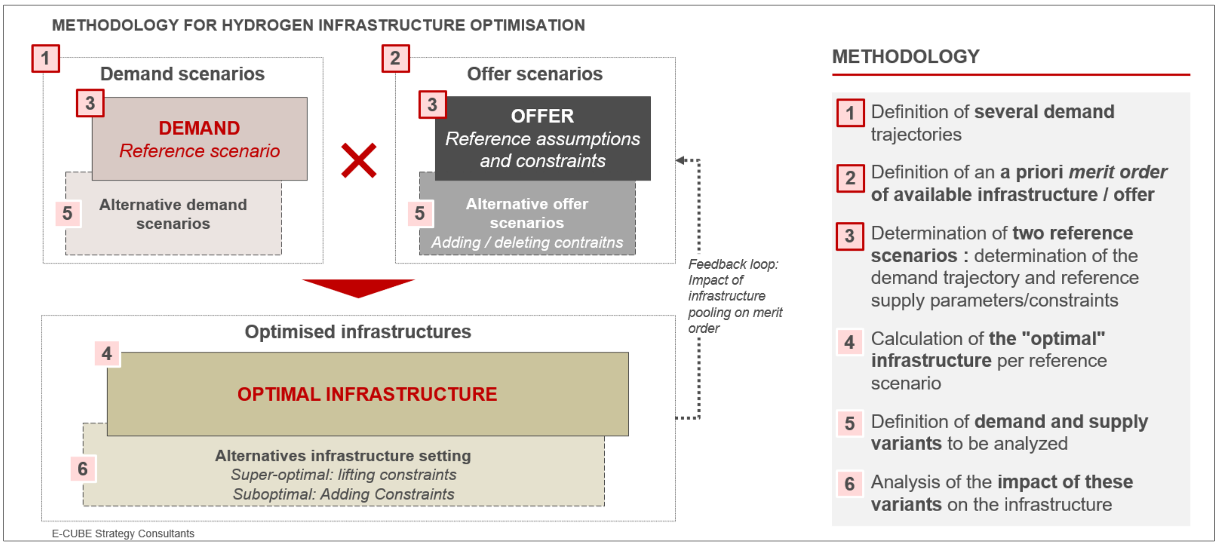


Figure 10 - Methodology for hydrogen infrastructure optimisation for an industrial park



E-CUBE Strategy Consultants is a tier-1 strategy consulting firm exclusively dedicated to energy and environmental issues. We combine the strengths of proximity, responsiveness and flexibility of a small team with the excellence and experience of an international team.

Our three areas of expertise are:

- Energy & Environment: Supporting energy companies (electricity and gas companies, players in the New Renewables sectors, oil companies) in anticipating and taking into account the evolution of their market, regulatory, competitive and technological environment. Assist public and private actors in the evaluation or definition of their strategy in order to integrate the challenges and opportunities of an energy and environmental "new deal".
- Mobility & Infrastructure: Supporting public and private mobility players (automotive, road transport, rail, air transport, shipping, logistics) in the context of their strategic, regulatory and operational projects. Supporting industry leaders and local authorities in re-evaluating their strategy in order to integrate digital challenges and the rise of new models and uses. Assist investment funds in their acquisitions and equity investments.
- Decarbonization: Supporting industrial players and tertiary groups in understanding the impacts of the energy and environmental transition on their activities and business models. Support and challenge their decarbonization strategy (objectives and roadmap) and climate adaptation.

E-CUBE Strategy Consultants supports its clients on global issues from its offices in Paris, Lausanne and Brussels, and from partners and affiliates in its E-CUBE Global network.

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