Executive summary of
pre-feasibility study by Fluor for:

LARGE-SCALE INDUSTRIAL AMMONIA CRACKING PLANT

Commissioned by Port of Rotterdam Authority (PoR), Air Liquide, Aramco, bp, E.ON/Essent, ExxonMobil, Gasunie, Global Energy Storage (GES), HES International, Koole Terminals, Linde Gas, RWE, Sasol, Shell, Uniper, Vopak and VTTI.

Executive summary pre-feasibility study

LARGE-SCALE INDUSTRIAL AMMONIA CRACKING PLANT

Given the large interest in developing ammonia cracking facilities to enable the import of hydrogen for decarbonisation of the Industrial Complex in the Port of Rotterdam and other regions further afield, 18 parties joined forces to commission a pre-feasibility study for a large-scale industrial ammonia cracking plant. Port of Rotterdam Authority (PoR), together with Air Liquide, Aramco, bp, E.ON/Essent, ExxonMobil, Gasunie, Global Energy Storage (GES), HES International, Koole Terminals, Linde Gas, RWE, Sasol, Shell, Uniper, Vopak, and VTTI commissioned Fluor to perform this pre-feasibility study.

The study investigated the possibilities for a large central ammonia cracking facility to generate hydrogen from imported ammonia in the Port of Rotterdam, with a capacity of 1 million tons of hydrogen per year (equivalent to ~3000 ton/day or 1.3 million Nm^3/h of H_2). This results in an approximate consumption of 20,000 tons of ammonia (NH_3) per day.

In addition to the ammonia cracking process plant, the study also looked at possible setups for the storage and distribution of the ammonia imported into the Harbour Industrial Complex (HIC).

The key aims of the study were to get a first understanding of the technologies available on offer, how far these processes are developed for commercial deployment, the energy and utility consumption of such processes, the number of process trains required to achieve the desired H_2 capacity (related to the maximum feasible per-train capacity), environmental footprint / emissions, general plot space requirements, safety and logistics associated with ammonia storage and handling, capital and operating cost of the required facilities, and the benefits of a central large scale ammonia cracking facility versus several smaller decentralised plants. The figures below provide a brief example of this.

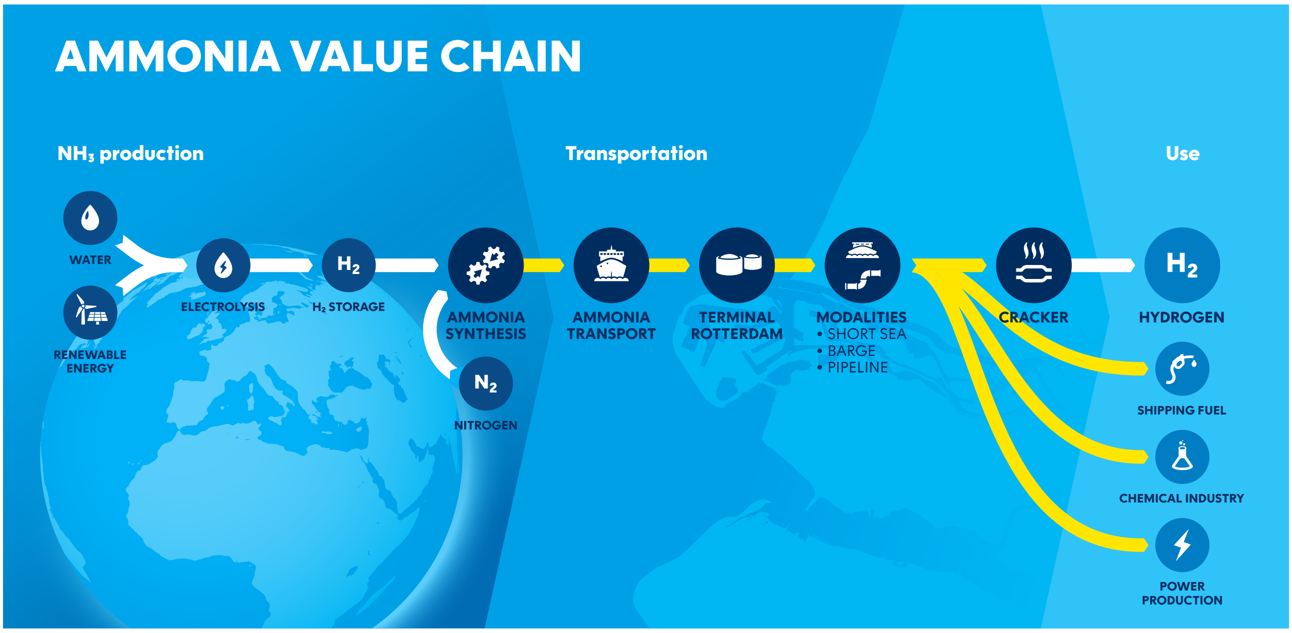


Figure 1 —
Overview of the ammonia value chain

Ammonia cracking is an endothermic equilibrium reaction requiring external heat supply. The study looked at ammonia cracking technology from Haldor Topsoe, KBR, Thyssenkrupp, Johnson Matthey, Duiker, Casale and H2SITE.

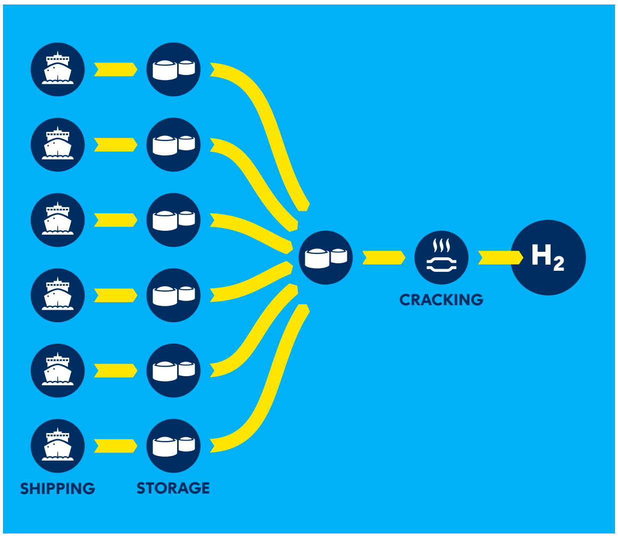
Most licensors have technology available today to provide ammonia cracking plants of capacity, using several parallel process trains. Whereas many of the licensors offer process designs based on conventional 'reformer' technology (vertical catalyst filled tubes in a firebox with radiant heat transfer to the process tubes) as employed in grey hydrogen production, ammonia production, and methanol production plants, notable differences were also observed in the overall flowsheet and in the core reactor section. Duiker's technology employs catalyst-filled tubes in an alternate configuration to prevent direct exposure to flames. H2SITE's technology consists of a reactor column filled with catalyst, containing Pd-based membranes. All licensors confirmed that they could provide the required H_2 product purity and pressure of 99.9 mol% and 50 barg. The various technologies have TRL levels of 6-9.

Safety

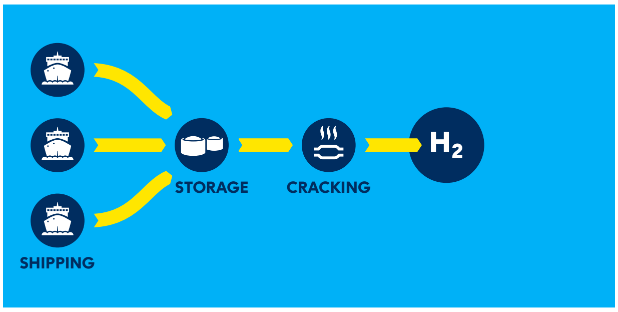
Previous studies commissioned by the Port of Rotterdam have found that the import, storing, and transporting of large amounts of ammonia can be done efficiently and safely within the safety contours of the Port. Moreover, companies in the HIC have the experience and skills to handle different chemical substances and dangerous goods. That said, the focus of all participants of this study is to ensure that the use and transportation of ammonia will be done safely. This means that the safest transport routes need to be researched and used and that the safety requirements around the cracking process also need to be researched further. In the study, ammonia transportation via pipeline and the best available technology for Ammonia storage have been included.

Centralised and decentralised options

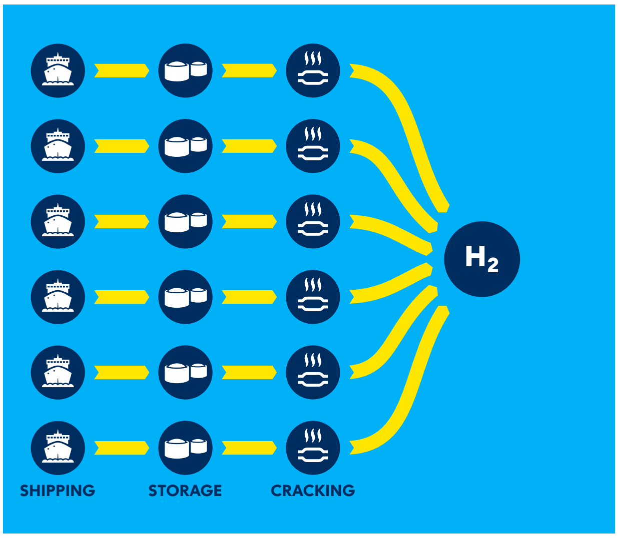
Schemes for ammonia offloading and storage logistics for centralised and de-centralised cracking options were developed. Given that determining the location of these plants was not part of this study, three plausible options were identified:



Option 1
Centralised ammonia cracker with ammonia offloading and storage at six different locations.



Option 2
Centralised ammonia cracker with ammonia offloading and storage at the same location; size of storage tanks based on those typical today with potential optimisation in the future.



Option 3
Six decentralised ammonia cracker plant locations, each with its own ammonia offloading and storage facilities.

Space requirements

The plot space requirements including storage as estimated by Fluor based on the information from the various licensors for the entire 1 million tons of hydrogen capacity range between 200,000 m^2 and 450,000 m^2. These are conservative estimates. It is not typical for licensors to provide well-developed plot plans for such a high-level study. The plot space requirements can be further optimised once the potential plant location(s) have been determined.

Costs

The capital cost of an ammonia cracking plant is considered roughly equal for central and decentral options. This is because, for most licensors, the number of parallel trains required is so high that there should not be a major capital cost difference between having the same number of trains all at one location, or at six different locations. However, with advances in ammonia cracking technology, a greater amount of ammonia may be cracked in one train, reducing the overall number of trains. This would benefit a central facility in reducing capital investment resulting from economies of scale.

In addition, there are capital benefits of centralisation for ammonia storage and logistics. Hydrogen compression at a centralised location is less capital intensive as the number of equipment items is governed by the compression duty required instead of sparing of equipment. Utility systems can be centralised and constructed in one location.

Despite the substantial investment in the cracker and the storage, it was found that approximately 80-90% of the cost of H_2 production (starting from fixed ammonia prices delivered at the port of Rotterdam) lies in the cost of NH_3 feedstock.

Emissions

There are no CO_2 emissions from the plant as the designs were based on the exclusive use of carbon-free fuel. The required flue gas NOx (expressed as NO_2) specification of 80 mg/Nm^3 on a dry, 3 vol% O2 basis could be met by all licensors by the application of Selective Catalytic Reduction technology, indicating that the production process can be operated within the stipulated environmental limitations.

Conclusions

The study helped gain insight into the ammonia cracking technology landscape and made it clear that the technology for producing 1 million tons of hydrogen from ammonia is available today and requires a multi-train facility. The various trains may be located at a centralised plant or dispersed across several locations. There are clear capital cost benefits associated with building a centralised ammonia cracking plant with offloading and storage facilities at the same location. This does require a significant investment. However, the bulk of the cost of H_2 production from ammonia cracking (at the feedstock prices assumed in the study) lies in the cost of ammonia feedstock.

As a follow up to this work and to further develop this project, a more detailed licensor evaluation study must be carried out for an ammonia cracking plant with a defined plant location, capacity per location, and associated ship offloading & storage locations. A quantified safety / risk analysis study for the same including dispersion modelling calculations will enable greater insight into the environmental friendliness of the process.