Project Puffin

End-report
Date: June 11, 2025
Data of project Puffin:

- Project number: DEI121062, Project Puffin
- Koninklijke Vopak N.V., penvoerder Vopak Hydrogen Plant B.V.
- Project period: May 26, 2022 - October 30, 2024

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Background of the project

During 2019, Vopak started with the development of a 1,5 ton per day over-land green hydrogen chain between Dormagen (Germany) and Rotterdam, together with technology partner Hydrogenious (Germany based). For this project, Vopak applied for a so-called DEI subsidy, which was granted. The name of the project was Project Puffin. This project was stopped In Q3 2024 due to various reasons.

Funding of the project

This project was carried out with a subsidy from the Ministry of Climate and Green Growth (KGG), National EZK and LNV Subsidies Scheme, Top Sector Energy, implemented by the Netherlands RVO (Rijksdienst voor Ondernemend Nederland).

Introduction Project Puffin

Green hydrogen is necessary to achieve the European climate goals. However, in Northwest Europe, we face a number of challenges regarding green hydrogen: 1) limited scalability when it comes to local production due to an unfavorable climate, 2) seasonal mismatch between supply and demand of green electricity (and therefore green hydrogen). To fill the gap in a future hydrogen system, large-scale import of green hydrogen is necessary for NW Europe.

To import hydrogen on a large scale in a cost-effective manner, new technologies are being examined. These new technologies all need to be scaled up. The main candidate technologies are: Liquid Organic Hydrogen Carrier (LOHC), (green) Ammonia, and liquid hydrogen. Vopak is looking at all three technologies and expects that, depending on the end markets, all of them will be needed to provide the necessary quantities of green hydrogen. Vopak sees many advantages in LOHC technology due to its expected short-term implementation possibilities. Much of the existing infrastructure can be reused. The technology based on Benzyl Toluene, developed by Hydrogenious Technology from Germany, offers particular ease in transport and storage: it is a so-called K3 product (like diesel, BT is a type of heating oil) and can in principle be stored in conventional tanks and transported with conventional means of transport (e.g. existing ships, trucks).

This pilot is expected to provide valuable information for Vopak and Hydrogenious and is a significant scale-up from the current 24 kg per day at a hydrogen filling station in Erlangen, Germany (see images next page) to 1.5 tons per day in Rotterdam.

The pilot location is on the site of an existing Vopak terminal. This provides Vopak with a unique position in the hydrogen market with a "first mover advantage", a steep learning curve, and an acceleration for subsequent projects.

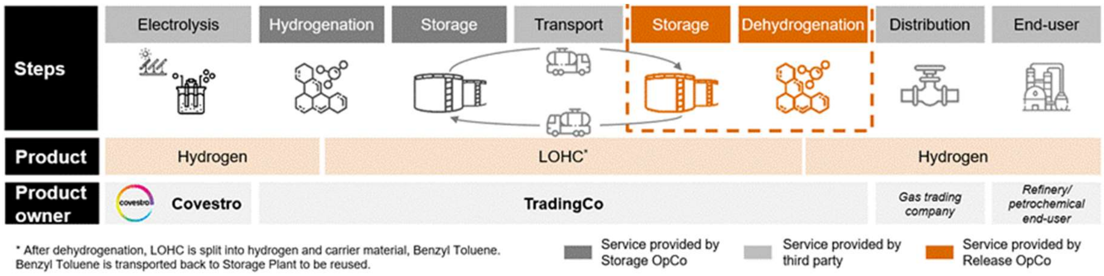
The Puffin Pilot is part of a hydrogen import chain of 1.5 tons per day. The technology used is new and developed by the German company Hydrogenious Technologies. The hydrogen is attached to a carrier (hydrogenation), transported by truck to the destination, after which the hydrogen is detached from the carrier (de-hydrogenation) by adding heat. The unloaded carrier goes back to the hydrogenation plant to be loaded with hydrogen again. The carrier circulates in the system and is repeatedly used for transport. The carrier can be considered part of the logistics system/infrastructure.

Although significantly scaled up, Puffin is still too small in scale to be profitable, but a necessary step to further scale up to volumes that can be profitable (expected from 100-200 tons per day).

For this project, a subsidy was requested under the DEI+ program, which was granted by RVO.

The process in the Puffin chain

The hydrogenation of the carrier in this particular chain takes place in Germany (Dormagen), where the hydrogen, sourced from Covestro, is bonded to a larger molecule: the carrier Benzyl Toluene (BT). The BT loaded with hydrogen is then transported from Dormagen to Rotterdam by road, using conventional trucks. In Rotterdam, at the Vopak Europoort terminal, the hydrogen is extracted through heating (de-hydrogenation). The unloaded BT returns to Dormagen to be hydrogenated again. This chain is shown graphically below.



Components in the Puffin hydrogen chain

The following companies/components play a role in the chain to be developed:

1. **Covestro** in Dormagen for the supply of green hydrogen. At this production site, hydrogen is a residual product for Covestro. Covestro wants to supply hydrogen to the project under attractive conditions. Using renewable energy for Covestro's energy supply, the hydrogen can be classified as green. Covestro is, like Vopak, a shareholder of Hydrogenious.
2. The so-called **Storage plant** in Dormagen, where the hydrogenation of the BT takes place. This plant will have a production capacity of 5 tons of hydrogen per day. The production capacity of this Storage plant will be ramped up from 1,5 to 5 tons per day in 3 years. For the first 3 years, 1,5 tons per day of the hydrogen produced will be supplied to Puffin. After this period, the full 5 tons per day will be supplied to a larger project in Germany: Blue Danube, that intends to supply to a local refinery.The intention was for Hydrogenious and Vopak to jointly have a stake in this Storage plant, with Hydrogenious having a majority. This plant has been granted a subsidy by the state of North Rhine-Westphalia (NRW).
3. The **transport** of the loaded (hydrogenated) and unloaded (de-hydrogenated) carrier between Dormagen and Rotterdam. Road transport is done with **conventional trucks**. The hydrogenated carrier is loaded in Dormagen and unloaded in Rotterdam for dehydrogenation. The de-hydrogenated carrier material will be transported back to Dormagen for re-hydrogenation. With further scaling up, the intention is that the transport of the carrier material will take place by ships (from within and outside Europe).
4. The so-called **Release plant** in Rotterdam, where the dehydrogenation takes place. By heating the carrier material to ~300 degrees Celsius, the hydrogen is extracted from the carrier material.

Scope of the DEI+ Subsidy

The scope for the DEI+ subsidy is limited to the Release Plant in Rotterdam as part of project Puffin. In Germany, the so-called storage plant in Dormagen, where the LOHC is hydrogenated, has also received a subsidy (see previous paragraph).

Purpose of the Project

The purpose of this pilot is to achieve a scale-up that moves towards industrial scale and is integrated into an existing industrial complex (i.e., an already operational storage terminal). After this scale-up, another scale-up step (20-50 tons/day) is expected to be necessary before the scale can be achieved that could operate without subsidy and with sufficient profitability.

The improvement points will lie in both the CAPEX per kg H2 and the reduction of the OPEX per kg H2. Regarding CAPEX, there are primarily learning points in the design of the plant, the material usage, optimizing tank design and the construction. Regarding OPEX, the greatest potential for improvement lies in optimizing energy consumption during dehydrogenation. Also, fitting of additional permit requirements within the permits of an existing terminal is a learning point (for Vopak, but also for DCMR for whom BT is a new substance).

This pilot and its successors contribute to Vopak's ambition to facilitate large-scale hydrogen import, largely via existing infrastructure, such as tanks, pipelines, ships, truck loading facilities, etc. Vopak believes that with this technology, it can bring the necessary flexibility to the future energy system. All of this is in line with the objectives in the Climate Agreement.

Intended Learning Points

- Scaling up the release unit to the next achievable level at stable operations.
- Integration into an existing industrial environment (demonstrate that it works).
- Gaining experience with an international logistics chain.
- Gaining experience with a relatively new and unknown (to authorities and to Vopak) substance (Benzyl toluene H/D).
- Achieving CAPEX reduction per kg H_2 compared to the current scale.
- Achieving OPEX reduction in reducing energy consumption.
- Achieving OPEX reduction by increasing the number of cycles that the carrier (BT) can be used.

Project progress

The project had a difficult start, with the start date being postponed by 6 months to May 26, 2022. The main reason for this was the progress of the German part of the project: the storage plant in Dormagen, which was on the critical path.

The initial intended location in Rotterdam was the Vopak terminal at the Chemiehaven, where Vopak could adapt small existing tanks for the storage of the carrier material and which was also close to a future hydrogen pipeline. However, on November 17, 2022, the Botlek terminal Vopak, to which the Chemiehaven terminal belongs, received a letter from Stedin that expansion of the capacity w.r.t. the power connection would not be possible until the period 2027-2029. Since the Chemiehaven terminal already operated at its maximum connection capacity and expansion would be needed for the project, Vopak had to switch to another location with space in terms of connection capacity (and land). In December 2022, it was decided to switch to the Vopak Europoort terminal (which at that time still had space in terms of connection capacity). Part of the work, including the basic engineering by Worley, had to be redone.

Another source of delay thereafter was the obligation, due to a subsidy for the German installation in Dormagen, to tender in Europe.

The engineering and the application for the permit in Dormagen were also delayed. An important aspect here was the novelty of the hydrogen carrier (Benzyl-toluene H/D) for the authorities, which, like in the Netherlands, is currently designated as a so-called ZZS (potentially very concerning substance), for which a multitude of safety measures are required until this substance has received a full so-called REACH registration (from this registration, the assumption is that BT can be treated with safety measures comparable to diesel).

Meanwhile, the costs of the project have increased due to significant wage cost increases, rising material costs, and costs of additional measures due to unexpected scale-up issues (learning points of the project). This was mainly reflected in the engineering costs of the reactor (the ISBL) and partly in extra costs of the connections and provisions between the reactor and the terminal (OSBL).

On the revenue side, the issue was that this was a pilot where it was not possible to guarantee delivery guarantees. As a result, no income from delivery proved possible. In response to this, two decisions were made:

1. The generated hydrogen should again serve as fuel to generate the energy required for the dehydrogenation process instead of electricity. During the start-up of operations, a small amount of natural gas or LPG is needed, after which the switch is made to the produced hydrogen.
2. Studies have been done to blend the hydrogen with natural gas at certain installations on the terminal that consume natural gas (such as the vapor treatment unit and a boiler house).

Option 1 has been incorporated into the final engineering. An important learning point here was that small benzene emissions could then occur. Additional emission-reducing measures were needed for this, which were also elaborated in the CAPEX, which therefore became somewhat higher.

Option 2 has the advantage that, if the installation fails, there is no problem for the hydrogen recipient because it is being blended. Another advantage is that the CO2 emissions of the terminal are reduced by blending the hydrogen into the natural gas.

Option 2 has not been further developed because the investments to make the necessary adjustments for blending were considerable, while due to all the delays, the operational period of the Puffin plant in Rotterdam was reduced from the original 3 years to a maximum of 1 year. This short period of operations does not justify the extra investment.

Reasons to stop the project

There is an accumulation of reasons to stop the Release plant within the Puffin project, as already shown above. In summary:

1. The Storage Plant in Dormagen is experiencing substantial delay due to the above-mentioned causes such as mandatory European tendering and the permit application.
2. This delay in the Storage Plant means that this plant can only supply hydrogen to the Pilot Release Plant in Rotterdam for a maximum of 1 year (2028), instead of the intended 3 years (2026, 2027 and 2028).
3. The hydrogen offtake possibility in Rotterdam is very limited due to the low volumes and the non-guaranteed delivery from the pilot; Vopak has investigated its own consumption at the terminal to reduce terminal emissions.
4. For the offtake options at the terminal, large investments are necessary that cannot be justified with an operational duration of only 1 year.
5. With the stopping of project Puffin, the 5-ton-per-day Storage Plant will supply all hydrogen to the 5-ton-per-day Release Plant of IPCEI project Blue Danube, which will supply the hydrogen to a refinery at the same location.
6. The costs of the project are much higher than the originally budgeted and submitted costs, especially in the area of the ISBL due to unexpected complexity and additional measures required to limit risks.

Overview of Deliverables Compared to Original Milestones

Milestone overview:

Milestones as indicated in the Puffin project application:

1. Detailed Engineering & Procurement - Result: detailed engineering, specification, and sourcing of long lead items, define and select scope of work contractors.
2. Preparation of site - Result: demolition, realization of foundations, piping, and electrical installations.
3. Installation of the Release Plant - Result: assembling, installing, and connecting the Release Plant.
4. Monitoring & Testing - Result: monitor and test results to accumulate knowledge on operating LOHC plants of this scale and improve the efficiency of the process.

A change request was submitted on June 28, 2023, with a shift of milestone 3 to 1 due to prepayment of the packaged unit (to be classified under procurement in milestone 1, procurement).

Before the subsidy period started, the application process for the permits was in progress. The lead time has been quite long, which was mainly due to the new, unknown carrier material. The final permit has been received (Feb 2025), with the relevant authorities now being well acquainted with the new substance, benzyl toluene. It is expected that this makes a permit application for follow-up projects based on the same technology easier.

Completed Work (per Milestone)

- Milestone 1:
  - Detailed engineering OSBL by an external engineering company.
  - Cost estimates completed.
  - Detailed engineering by suppliers of main equipment and Vopak engineering (Europoort terminal and Global engineering) completed.
  - Permit applied for and received.
  - Engineering for the ISBL is completed and paid for in milestone 1 (originally part of MP3 - packaged unit ISBL).
  - Application initiated for a “full REACH registration” for the Benzyl-toluene (by Hydrogenious) - in progress.
- Milestone 2:
  - Demolition work started, site delivered empty.
  - Test trenches dug as part of soil investigation.
  - Soil investigation completed.
- Milestone 3:
  - Down payment made ISBL packaged unit (see MS1).

Overview of realized learning points

Input from Hydrogenious and Vopak combined:

Technical:

- Design and construction of a first-of-its-kind 1.5t/d release plant, considering safe and reliable operation and compliance with regulatory requirements. This includes, but is not limited to:
    - Footprint and construction volume optimized system layout
    - Reactor layout and design with special attention to:
        - Material selection and strength analysis using FEM method;
        - Optimization of the dimensions of the reaction tubes, based on tests in Hydrogenious' technical center (inner diameter: 25 mm);
        - Optimization of flow rate (mass flow) and flow direction, based on tests in our pilot plant
    - Design of all auxiliary equipment (e.g. heat exchangers, heat recovery units, LOHC circulation pumps) with special attention to:
        - Minimized energy consumption during system operation
        - Reliability and simple operation by enabling a high degree of automation
    - Transfer of technologies for catalyst regeneration into applicable technique (automated rinsing routines, automated thermal cleaning cycles) and their integration into the release plant design
    - Development of a detailed operating and automation concept
    - State-of-the-art technical availability of the release plant (>95% acc. To Guideline VDI 3423).
- Identification of all site-specific and regulatory requirements and implementation of the resulting technical and organizational measures for the safe handling of LOHC.
- Obtaining the operating permit in accordance with Dutch law
- Identification and preparation of the organizational implementation of all measures necessary for an uninterrupted LOHC logistic chain. This includes, but is not limited to:
    - Determination and detailed planning of the technical and organizational requirements for safe and reliable handling of the goods at the Storage Plant (GER) and Release Plant (NL) locations
    - Technical equipment of the trucks, especially with regard to safety-relevant aspects of LOHC handling, for example the use of dry disconnect couplings,application of Nitrogen blanketing during transport
    - Size and specifications of the storage tanks for loaded and unloaded LOHC

Other (environmental/organizational):

- Dehydrogenated BT (BT-H/D) is an unknown, new substance to authorities (and Vopak). This is classified as SCC (Strictly Controlled Conditions), which requires the most stringent safety measures, unless a so-called full REACH classification is granted. This procedure has been accelerated by partner Hydrogenious, partly due to Puffin (substances handled and stored by Vopak must always have a REACH classification - company policy).

- A blueprint for the operating model and operating philosophy was designed by Vopak (including driver-operated loading), where the installation and associated facilities are controlled and monitored from the existing control room of the terminal in collaboration with a small control unit next to the release installation with truck loading bay.
- Integrating the installation into existing infrastructure and IT systems within Vopak or at the terminal, consisting of:
  - Adapting the reactor/release unit footprint (m2) to the assigned location;
  - Using existing infrastructure and utilities (i.e. nitrogen, electricity) as well as waste and surface water drainage systems;
  - Using existing tank technology, to be equipped with a nitrogen mixing installation to safely store the loaded and unloaded LOHC;
  - Integrate and manage the new facility using existing Vopak IT systems.
- Designing a RACI model for the operation of such a unit at an existing terminal (roles, responsibilities) and **who** (the terminal operators, Vopak Hydrogen Plant BV as operator of the release unit and the truck loading station, Hydrogenious as technology provider, Vopak engineering, etc.) **does what** in certain operational situations.

Way forward after Puffin

Although the Puffin project was stopped for good reasons, Vopak still believes in this LOHC technology developed by Hydrogenious. Vopak has applied for IPCEI funding and was rewarded with it for a larger project with the same technology: Northern Green Crane. This project has been stopped, due to an incomplete supply chain as a consequence of German withdrawal of a hydrogenation plant upstream.

At this moment, Hydrogenious is executing Blue Danube under IPCEI, a 5 tons per day release plant in Bavaria close to a refinery.