

## Industrial decarbonization in Dunkirk: pyrolysis

Janv.  
2024



AAP ZIBAC - 2.2.2 Dkarbonation –  
Public summary - GRDF

### 1. Strategic context and decarbonization challenges

The ZIBAC (Low-Carbon Industrial Zones) program is part of the France 2030 investment plan, which aims to accelerate the ecological transformation of major French industrial hubs in order to strengthen their competitiveness and attractiveness. In this context, the Dunkirk industrial-port zone is a priority area due to its significant share of national industrial emissions. The Dunkirk basin accounts for approximately 13.7 million tons of CO<sub>2</sub> per year, representing nearly 20% of French industrial emissions. Decarbonizing this zone is therefore a key lever for achieving national and European climate goals.

The decarbonization strategy of local industries is based on several complementary approaches, including energy efficiency, transformation of the energy mix, adoption of new industrial technologies, and carbon capture for emissions that are difficult to reduce. In this context, low-carbon hydrogen appears to be a key energy vector, particularly for major industrial players in the region such as ArcelorMittal, whose hydrogen demand is estimated at between 125,000 and 150,000 tonnes per year.

Currently, the main solution being considered to meet this demand is hydrogen production through water electrolysis. However, this technology still involves high costs, especially for energy-intensive industrial uses such as steelmaking. The study therefore examines the relevance of an alternative technology: methane pyrolysis, which enables the production of low-carbon hydrogen at a potentially lower cost while generating solid carbon that can be valorized as an industrial co-product.

### 2. Objectives and methodology of the study

The purpose of the study is to evaluate the technical, economic, and industrial feasibility of a hydrogen production project based on methane pyrolysis on the industrial platform of Dunkerque. It also aims to determine whether this technology can be integrated into the local energy strategy and contribute to the decarbonization of industrial activities.

The methodological approach is based on three areas of analysis. The first consists of establishing a state of the art of pyrolysis technologies and the industrial players involved. This work includes a technological benchmark as well as an analysis of the industrial maturity of the available processes. It also examines energy performance, required investment levels, operating costs, and the efficiency of the different technologies.

The second area focuses on analyzing the technical, environmental, and economic dimensions of a potential project. The study compares methane pyrolysis with the main competing hydrogen production pathways, such as alkaline electrolysis, PEM electrolysis, and steam methane reforming with carbon capture. It also analyzes the constraints related to hydrogen distribution, storage, and integration into existing infrastructure.

The third area aims to identify local industrial opportunities for structuring a turquoise hydrogen sector in the region. This analysis includes identifying potential markets for both the hydrogen produced and the solid carbon generated by the process. Interviews were conducted with several industrial companies in order to assess their needs, technical constraints, and purchasing criteria.

### 3. Technological principle of methane pyrolysis

Methane pyrolysis is a thermochemical process that consists of decomposing methane into hydrogen and solid carbon in the absence of oxygen. This endothermic reaction requires a supply of heat or electricity to break the molecular bonds of methane. The process produces two main streams: hydrogen, which is the desired energy product, and solid carbon, which can be valorized in various industrial applications.

This pathway is generally associated with so-called “turquoise” hydrogen, which is characterized by an environmental profile intermediate between green hydrogen and grey hydrogen. It consumes less electricity and water than water electrolysis while generating a valorisable co-product, which can improve the economic viability of the process.

Pyrolysis technologies can be divided into several categories depending on the heating method used. The main categories include plasma pyrolysis, catalytic pyrolysis, processes using molten metal or molten salt baths, thermal processes, and certain emerging technologies using microwaves or solar energy. Each of these technologies presents specific characteristics in terms of efficiency, product purity, and industrial maturity.

### 4. Technological maturity and industrial players

The methane pyrolysis market is currently dominated by start-ups and innovative SMEs rather than large industrial groups. Among the most advanced projects, the American company Monolith stands out as the only player to have reached large-scale commercial production through a plasma pyrolysis technology. Its industrial site produces approximately 2,500 tonnes of hydrogen per year as well as 14,500 tonnes of carbon black.

Other players are currently developing pilot projects or industrial demonstrators. Hazer Group in Australia is developing a catalytic process with a pilot reactor, while BASF is exploring a thermal technology as part of a research project in Germany. Initiatives using molten metal baths or solar technologies are also underway, but they remain at lower levels of technological maturity.

Overall, pyrolysis technologies have not yet demonstrated their ability to be deployed on a very large scale. Their industrial maturity remains lower than that of electrolysis technologies or steam reforming with carbon capture, which constitutes one of the main risks associated with their industrial deployment.

### 5. Market and valorization of solid carbon

The economic development of methane pyrolysis strongly depends on the valorization of the solid carbon produced during the process. This carbon can be transformed into several industrial materials, notably carbon black, graphite, or specialized carbons used in batteries, inks, or composite materials.

Solid carbon markets can be divided into two categories. Current markets are characterized by high value-added products but relatively limited volumes. Future markets could involve low value-added but very large-scale applications such as construction materials or metallurgy.

Carbon black currently represents one of the most important market outlets. It is mainly used in the rubber industry, particularly for tires, where it accounts for between 20% and 30% of the composition of a tire. Market prices generally range between €1.2 and €2 per kilogram depending on quality and market conditions.

Graphite represents a second strategic market, particularly for lithium-ion batteries. This material is used for anodes and accounts for more than 90% of the composition of certain electrodes. The global graphite market is heavily dominated by China, creating supply security challenges for Europe.

However, the potential volumes of solid carbon resulting from large-scale hydrogen production through pyrolysis could far exceed the current size of existing markets. By way of illustration, if all global hydrogen production relied on pyrolysis, it would generate approximately 300 million tonnes of solid carbon per year, whereas the current market is estimated at around 26 million tonnes by 2030.

### 6. Sizing of a potential project in Dunkirk

Given the current level of technological maturity, it appears unrealistic in the short term to consider a very large-scale methane pyrolysis project on the ZIBAC industrial zone of Dunkerque. The most advanced projects worldwide still remain relatively modest in terms of production capacity.

The study therefore proposes a reference scenario based on a facility producing approximately 5,000 tonnes of hydrogen per year as well as 15,000 tonnes of solid carbon. This capacity would correspond to an energy production of around 167 GWh of hydrogen per year, which would make it possible to supply several medium-sized industrial sites on the industrial platform.

This sizing is considered realistic because it remains smaller than the electrolysis projects planned in the area while still being large enough to meet the energy needs of certain local industrial players.

## **7. Environmental and technical analysis**

From an environmental perspective, hydrogen production through methane pyrolysis demonstrates intermediate performance between green hydrogen and grey hydrogen. The carbon footprint of the process mainly depends on the electricity used to provide the heat required for the reaction, as well as the natural gas consumed as feedstock.

Compared with electrolysis, pyrolysis offers several operational advantages. It consumes significantly less electricity and almost no water. For example, for a facility producing 5,000 tonnes of hydrogen per year, electricity consumption would be approximately 65 GWh, compared with around 260 GWh for an electrolyzer of equivalent capacity.

However, the energy efficiency of the process remains lower than that of electrolysis, and the carbon footprint strongly depends on the composition of the gas used. Integrating biomethane into the feedstock mix could significantly improve the carbon balance and could even lead to negative emissions if the proportion exceeds approximately 25%.

## **8. Economic analysis and competitiveness**

The economic analysis shows that the production costs of turquoise hydrogen mainly depend on the price of natural gas and the valorization of the solid carbon produced. Initial investments remain relatively high due to the low technological maturity and the lack of industrialization of the processes.

Operating costs represent the dominant share of the total production cost. Unlike green hydrogen, whose costs mainly depend on electricity prices, turquoise hydrogen has a cost structure divided between electricity and natural gas, which reduces dependence on a single energy source.

Economic projections indicate that turquoise hydrogen could become competitive by 2030 if solid carbon is valorized at around €1 to €1.5 per kilogram. In this scenario, production costs could become comparable to those of unsubsidized green hydrogen.

However, the competitiveness of this sector could be affected by the emergence of a European hydrogen market. The European Hydrogen Backbone infrastructure project plans to build a 40,000-kilometer hydrogen transport network by 2040, enabling hydrogen to be transported over long distances at an estimated cost of around €0.2 per kilogram for 1,000 kilometers.

## **9. Industrial stakeholders and local market opportunities**

Interviews conducted with industrial stakeholders in the region show that potential hydrogen demand exists but remains uncertain. Several companies, including ArcelorMittal, Imerys, and Ascometal, view hydrogen as a potential decarbonization lever, but they remain cautious regarding costs, technological risks, and the industrial process modifications required.

ArcelorMittal nevertheless appears to be the main future hydrogen consumer on the Dunkirk industrial platform, particularly within the framework of its direct reduced iron projects. Potential demand could reach several thousand gigawatt-hours per year by 2030.

On the solid carbon side, several companies have expressed potential interest, including Michelin, GrafTech, Aluminium Dunkerque, and Armor Group. However, technical requirements and pricing constraints vary significantly depending on the application, which complicates the structuring of the market.

#### **10. Business models and risks**

The development of a methane pyrolysis project involves several major risks. The first concerns the still limited technological maturity of the sector. The second relates to economic risks associated with the high level of investment required and uncertainty regarding natural gas and solid carbon prices. The third concerns the need to secure long-term purchase agreements for both hydrogen and carbon in order to ensure the profitability of the project.

The study identifies several possible business models. The model considered most relevant in the short term is based on a project led by a major industrial company or an energy provider capable of financing the investment and managing industrial risks. An alternative would be to entrust the project to a technology developer, but this option involves greater financial risks due to the generally limited size of these companies.

#### **11. Strategic recommendations**

The study concludes that the implementation of a methane pyrolysis project in Dunkerque by 2030 is feasible, provided that several key success factors are achieved. The first condition is the industrial development of the technology and the demonstration of its reliability at large scale through international pilot projects.

The second condition is the confirmation of sufficient industrial hydrogen demand on the industrial platform beyond the needs already identified. The third condition concerns the existence of viable industrial outlets for solid carbon in order to ensure the economic balance of the project.

Finally, the success of the project will also depend on a favorable regulatory framework and the clear integration of methane pyrolysis into the regional decarbonization strategy. Coordination between industrial, energy, and institutional stakeholders appears to be a determining factor in structuring this new industrial sector.

## RÉSUMÉ

This study analyzes the potential of methane pyrolysis as a low-carbon hydrogen production solution within the low-carbon industrial zone (ZIBAC) of Dunkerque, a key territory for French industrial decarbonization. The objective is to evaluate the technical, economic, and industrial feasibility of this technology in order to complement existing hydrogen production solutions and meet the growing needs of local industries.

Methane pyrolysis enables hydrogen production by decomposing methane in the absence of oxygen while generating solid carbon that can be valorized as an industrial co-product. The study compares this technology with the main existing production pathways, such as electrolysis and methane reforming with carbon capture. It also examines the conditions required for the emergence of a local industrial sector, including market opportunities for hydrogen and solid carbon, as well as the associated technical, regulatory, and economic constraints.

The results indicate that a medium-scale industrial project could be feasible in Dunkerque, with a production capacity of approximately 5 kt of hydrogen per year, provided that industrial market outlets are secured and solid carbon can be effectively valorized. The competitiveness of this sector mainly depends on the price of natural gas and the economic valorization of solid carbon.

The study concludes that methane pyrolysis could constitute a complementary solution for industrial decarbonization, provided that industrial demand, the technological ecosystem, and the regulatory framework are further strengthened.

### Ce document est diffusé par l'ADEME

#### ADEME

20, avenue du Grésillé

BP 90 406 | 49004 Angers Cedex 01

### CITATION DE CE RAPPORT

Toute représentation ou reproduction intégrale ou partielle faite sans le consentement de l'auteur ou de ses ayants droit ou ayants cause est illicite selon le Code de la propriété intellectuelle (art. L 122-4) et constitue une contrefaçon réprimée par le Code pénal. Seules sont autorisées (art. 122-5) les copies ou reproductions strictement réservées à l'usage privé de copiste et non destinées à une utilisation collective, ainsi que les analyses et courtes citations justifiées par le caractère critique, pédagogique ou d'information de l'œuvre à laquelle elles sont incorporées, sous réserve, toutefois, du respect des dispositions des articles L 122-10 à L 122-12 du même Code, relatives à la reproduction par reprographie.