ENERGINET

FEASIBILITY STUDY

HYDROGEN TRANSMISSION INFRASTRUCTURE IN JUTLAND

INTRODUCTION AND BACKGROUND

In this report, Energinet present the results of the feasibility study for a hydrogen infrastructure in Jutland connecting a hydrogen storage facility at Lille Torup to potential hydrogen production areas and to Germany. The feasibility study represents Energinet's first steps in building a hydrogen "backbone" infrastructure and had applied knowledge and competencies to the field of hydrogen for the benefit of the green transition and to support the political ambitions for the energy sector. The results of the study show that the prospects for a hydrogen infrastructure are good, but also that many challenges need to be solved in a future maturation project.

Between June 2022 and March 2023, Energinet conducted a feasibility study of a hydrogen transmission infrastructure in Jutland ("hydrogen infrastructure") to connect hydrogen production and consumption areas to a possible hydrogen storage facility in Lille Torup and to Germany. The initiation of the feasibility study was based on the previous government's agreement called "Development and promotion of hydrogen and green fuels" (the PtX agreement) of March 2022. The aim of the feasibility study was to make a recommendation as to whether to launch a maturation project for a hydrogen infrastructure based on the results of the feasibility study, particularly in relation to the socio-economic value of establishing a hydrogen infrastructure.

In addition, we acquired extensive knowledge about hydrogen and the hydrogen infrastructure, which does not exist on a large scale in Denmark today. This includes technical conditions, market conditions and financial conditions. Examples include the basis for technical design, the possibility of converting parts of the methane infrastructure to hydrogen, insights into financing and business models and market frameworks for use of the hydrogen infrastructure.

The market dialogue[1] conducted in 2022 showed considerable interest among market participants in exporting hydrogen to the German market. That is why Energinet, alongside the feasibility study, started a cooperation with Gasunie Deutschland concerning a cross-border hydrogen infrastructure. On each side of the border, we have submitted the projects to Projects of Common Interest[2] to qualify the projects for EU funding. In addition, our cooperation includes coordination of technical and market-related activities.

The political ambitions to exploit the considerable RE potential in and around Denmark, on which the production of green hydrogen will be based, are closely linked to European ambitions set out in initiatives like the European Hydrogen Backbone[3] vision of a coherent European hydrogen network and in the recently published Oostende Declaration[4], in which the gas TSOs make their competencies and resources available for exploiting the enormous potential for wind energy in the North Sea.

[1]Market dialogue about hydrogen infrastructure
[2]Projects of Common Interest (europa.eu)
[3]European Hydrogen Backbone
[4]Oostende Declaration

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RESULTS OF THE FEASIBILITY STUDY

Energinet contribute to converting energy systems with the aim of ensuring that citizens and companies use renewable energy for everything, with a continued high level of security of supply and reasonable affordability. That is what we call the energy trilemma. We must create value for society in a broad sense, for citizens, businesses, institutions and civil society

If the political ambitions for the expansion of renewable energy (RE) and PtX are maintained, the feasibility study shows significant socio-economic value in establishing a hydrogen infrastructure compared to a situation without a hydrogen infrastructure. The socio-economic benefits will mainly accrue to the Danish electricity and hydrogen producers, and most of the green hydrogen produced in Denmark is expected to be exported to Germany.

From the corporate economic perspective, the establishment and operation of a hydrogen infrastructure are expected to be challenging in the start-up phase, as the market will initially be under construction and the volumes transported will be low at first. This is because hydrogen production and consumption are an emerging market, and large volumes will probably not be achieved until 5-10 years after the infrastructure has been established. Work must continue in a maturation project to clarify corporate economic opportunities and risks, including analyses of developments in volumes, willingness to pay and cost scenarios, as these are key to corporate economic considerations.

Energinet's Board has given its conditional approval to launch a maturation project. The maturation project can launch immediately after the Minister for Climate, Energy and Utilities approves a maturation application.

INFRASTRUCTURE CONSIDERATIONS

Two hydrogen infrastructure solutions were examined, the "West Jutland backbone" and the "Central Jutland backbone". See Figure 1 . The report examined an expansion in phases, for example establishing the T-shape in Southern Jutland followed by a northbound infrastructure, either in Western Jutland going past the major electricity nodes or in Central Jutland running parallel with the existing natural gas pipeline.

The feasibility study analysed the capacity and operating conditions of the possible hydrogen infrastructure solutions.

The West Jutland backbone comprises a total pipeline section of around 360 km. For new pipelines, our analyses show that 36-inch pipelines with a design pressure of 80 bar are future-proof in terms of capacity. The methane gas pipeline in Southern Jutland, which could be converted, is 30-inch. Analyses show that this is no immediate capacity constraint.

The analyses also show that the hydrogen system can transport up to 3,000 MW of hydrogen production without compression and that capacity can be increased to between 7,000 MW and 10,000 MW if compression is used. The phased expansion of capacity is achieved by increasing the operating pressure in the system as the need for capacity increases. This is expected to be done with compressor stations installed by Energinet, where deemed necessary.

The hydrogen infrastructure contains a large volume of hydrogen. By allowing the system pressure to vary, it can be used as a medium-sized energy storage facility. The hydrogen system can thus be used to balance RE production in the electricity system if hydrogen production follows the RE production.

The feasibility study is also examining whether the Frøslev-Egtved II methane pipeline can be converted to transport hydrogen. The investigations are being performed in one of DNV's laboratories and involve material tests. The technical aspects are expected to be clarified and completed in the summer of 2023.

The preliminary construction budget estimate (CAPEX) is reckoned to be between DKK 10 and 22 billion (2023 prices) over the period 2025 to 2038. This covers pipeline infrastructure and connection facilities in the period 2025-2030 as well as compressor stations as required towards 2038. The estimate is based on the costs of recently laid Baltic Pipe and takes the rise in prices and a strained market situation for pipeline and construction works into consideration. It also reflects the fact that hydrogen infrastructure is expected to cost more because the technology is new

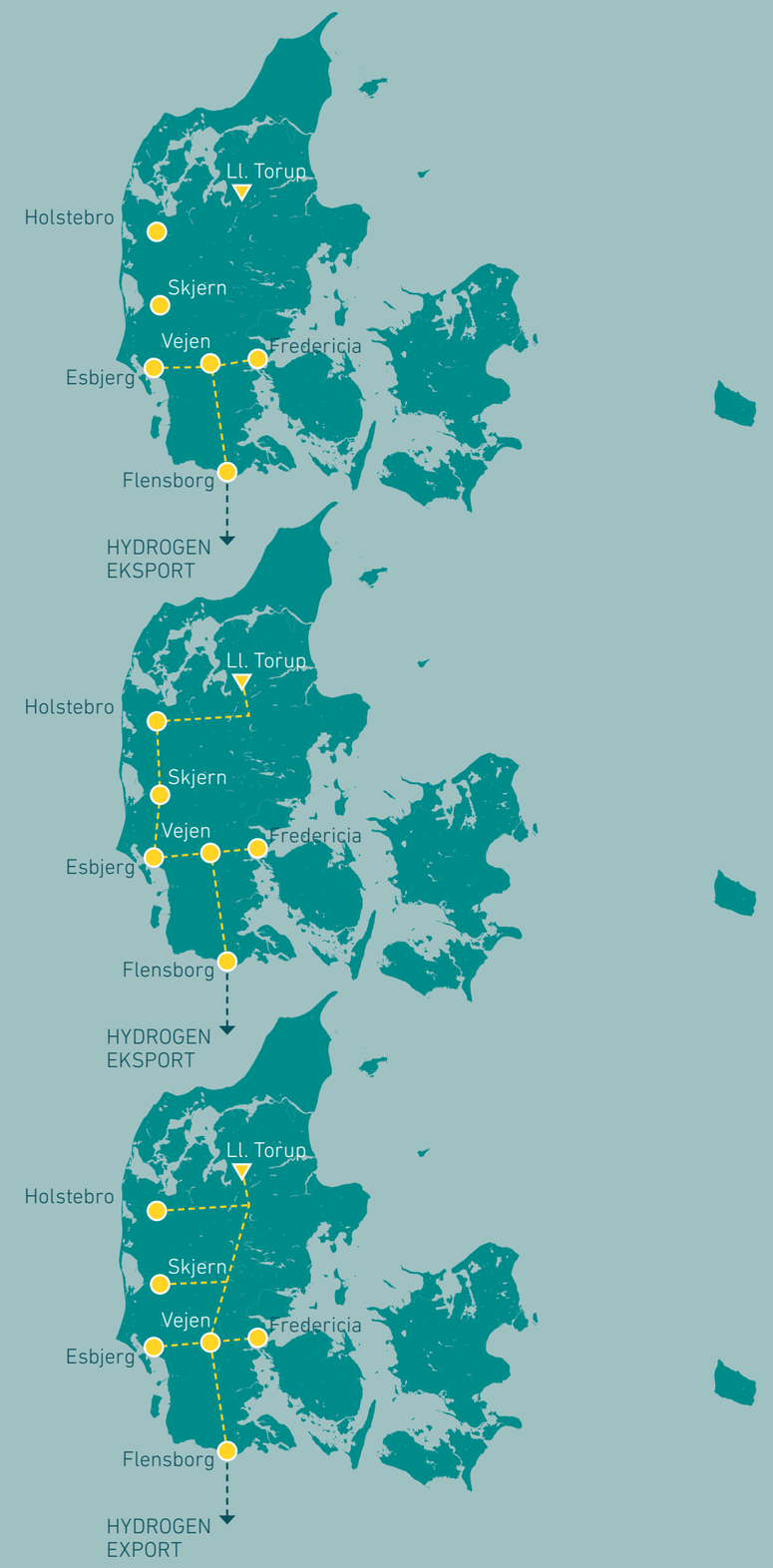


Figure 1 Possible hydrogen infrastructure solutions investigated in the feasibility study. The southern T shape is considered as the starting point. The transmission line runs past the major electricity nodes (yellow circles).

and immature, and that the supplier market is less mature than for methane infrastructure. The construction budget will be qualified further in the maturation project, for example through market dialogue with potential suppliers.

REGULATORY ASPECTS

Hydrogen and the hydrogen infrastructure are just as new for the Danish authorities as they are for Energinet. There has therefore been initial dialogue with the relevant authorities to discuss the approach to handling hydrogen and establishing a hydrogen infrastructure.

Initial dialogue has taken place with the Danish Environmental Protection Agency, which, as with other large construction projects, is the authority responsible for issuing a § 25 permit to establish a hydrogen infrastructure. Before that happens, an environmental impact assessment will be carried out, and the public will be involved in the process on two occasions. A § 25 permit allows the infrastructure owner to begin the process of acquiring rights for land and subsequent construction.

For the technical natural gas and biomethane plants, the Danish Working Environment Authority used to be the approving authority. This part of the Danish Working Environment Authority was transferred to the Danish Safety Technology Authority at the beginning of 2023. The Danish Safety Technology Authority is thus the approving authority for the technical facilities needed to establish a hydrogen infrastructure in Denmark. This applies to new facilities and the conversion of natural gas facilities. Energinet is in dialogue with the Danish Safety Technology Authority about how it envisages supervising and approving of the technical facilities.

There is a need for smooth and close cooperation between future infrastructure owners and authorities in a process involving binding commitments on how the market participants will use the infrastructure. There is no designated supervisory authority at present, and any uncertainty about these risks causing delays. For a future process with binding commitments on how the hydrogen infrastructure will be used, it is necessary to clarify which authority is to supervise the process. Energinet is in dialogue with the Danish Energy Agency about this.

As the owner of Energinet and in view of the size of the potential establishment project, the Minister for Climate, Energy and Utilities must approve a maturation application to launch the maturation project. In addition, the Minister must grant final investment approval (a so called §4 approval) before the establishment project is launched.

SOCIO-ECONOMIC ANALYSES

The socio-economic value of establishing a backbone in Jutland with a gradual phase-in towards 2030 was analysed based on the Danish Energy Agency's analysis assumptions for 2022 (AF22). Assumptions about the specific geographical locations of future PtX plants are based on input from the market dialogue, knowledge about current and potential PtX plants and the expectation that the PtX plants prefer easy access to the electricity supply by locating themselves close to the major nodes in the electricity transmission network.

The socio-economic effects of establishing a hydrogen infrastructure were analysed and quantified by measuring changes in consumer and producer surpluses, and congestion rents resulting from the non-establishment of a hydrogen infrastructure. The effects were calculated for all affected energy markets, in other words the electricity, hydrogen, heating, methanol and ammonia markets. In addition, there are several unquantified effects, primarily pre-emptive investments in electricity networks, unnecessary ancillary services, and effects such as the CO2 impact and the impact on the natural gas network.

If renewable and PtX capacity develops as described in AF22, the feasibility study's preliminary results show that there will be significant socio-economic benefits in the order of DKK 30-75 billion by 2060 if a hydrogen infrastructure is established in Jutland, compared with a situation without a hydrogen infrastructure. The large range in the estimated socio-economic benefits is the result of the reference scenario (AF22) and several sensitivity analyses. The socio-economic methodology is based on Energinet's "business as usual" for electricity and gas projects. The methodology must be further refined in the maturation project, for example in relation to quantification of dynamic effects. Other alternatives will also be investigated in the maturation project. The size of the socio-economic benefits will thus be recalculated in the maturation project.

The benefits of establishing a hydrogen infrastructure will mainly accrue to the electricity and hydrogen producers, whereas national consumers of hydrogen to produce ammonia and Danish electricity consumers will have to pay a slightly higher price. Congestion rents from the international connections will fall due the reduced load on the interconnectors when the energy is exported as hydrogen rather than electricity.

The expected RE and PtX capacity can be operated far more efficiently with access to the German market through the hydrogen infrastructure. The analyses show an increased load factor for PtX plants from about 1,000 hours if it is not possible to connect to the hydrogen infrastructure, up to 5,000 hours if the hydrogen infrastructure is connected. A hydrogen infrastructure is thus an important prerequisite in creating favourable conditions for large-scale RE and PtX in Denmark.

The sensitivity analyses applied to key assumptions showed that the socio-economic benefits are particularly affected

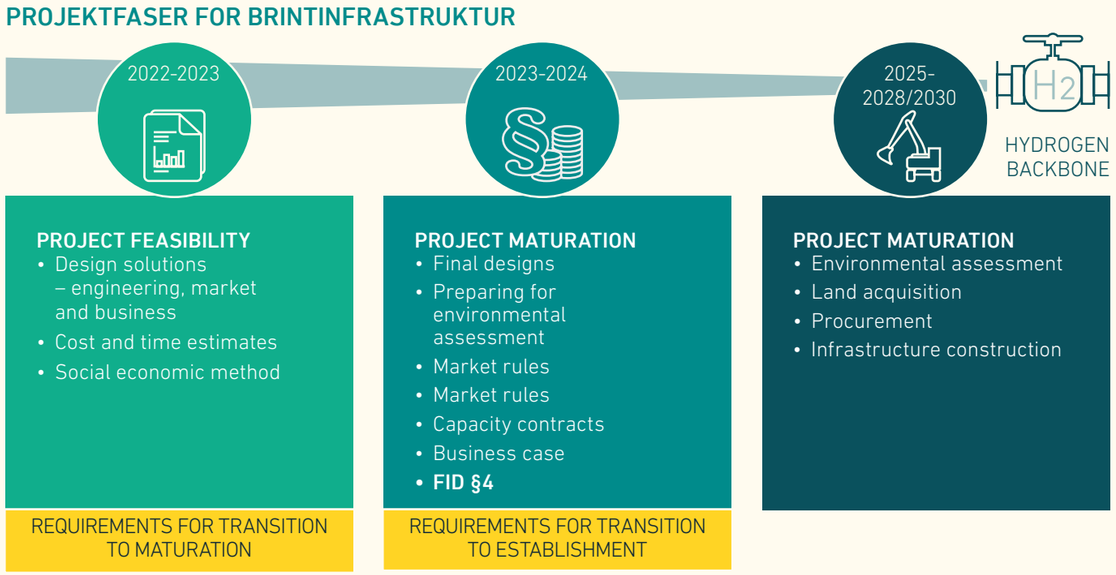


Figure 2 Timeline for establishment of a hydrogen infrastructure

by changes in the market prices of hydrogen, ammonia, and methanol and by expectations concerning German and Danish hydrogen consumption. The analysis is based on sustained developments in PtX and RE regardless of whether a hydrogen infrastructure is established. Other developments in RE and PtX which are more closely coupled with developments in electricity and hydrogen infrastructure will also have a major impact on the results. In general, the following conclusions can be drawn from the analyses:

- A hydrogen infrastructure increases demand for Danish hydrogen via the German market.
- A hydrogen infrastructure provides incentives to invest in PtX capacity.
- A hydrogen infrastructure helps Denmark become a net exporter of green energy.

Concerning the socio-economic analyses, an external review was carried out by the consultancy firm EA Energy Analyses. According to them, assumptions about prices, hydrogen consumption and alternative RE and PtX developments should be more market-based and should be linked to the size of the hydrogen infrastructure. The maturation project will continue to work on these aspects.

CORPORATE ECONOMIC ANALYSES

The corporate economic analysis was carried out to identify potential corporate economic challenges arising from investments in the hydrogen infrastructure, so that relevant mitigating measures can be identified and progressed early in the ongoing project work.

There is considerable demand for hydrogen infrastructure from commercial market participants. This was revealed by the market dialogue in which 96% of the projects stated that they need a hydrogen infrastructure. To put this into context, 97% of production from hydrogen-only producers is expected to be destined wholly or partly for export, which cannot happen without a hydrogen infrastructure. Note also that the demand for a hydrogen infrastructure is associated with uncertainty as hydrogen production is expected to be concentrated in relatively few large plants, with eight projects accounting for 87% of the electrolysis capacity in 2030 according to the market dialogue.

In the market dialogue, customers indicated a willingness to pay EUR 3-9/MWh for hydrogen transport in pipelines for most of the hydrogen volumes. In the corporate economic analysis, the upper figure of EUR 9/MWh is used as the willingness-to-pay indicator. The market participants themselves state that it is difficult for them to estimate the willingness to pay.

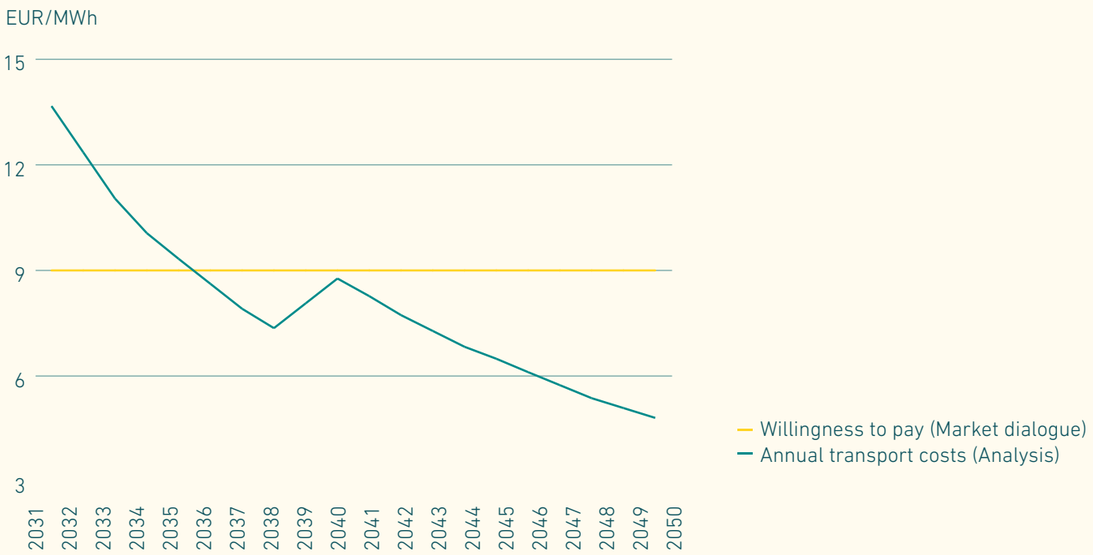
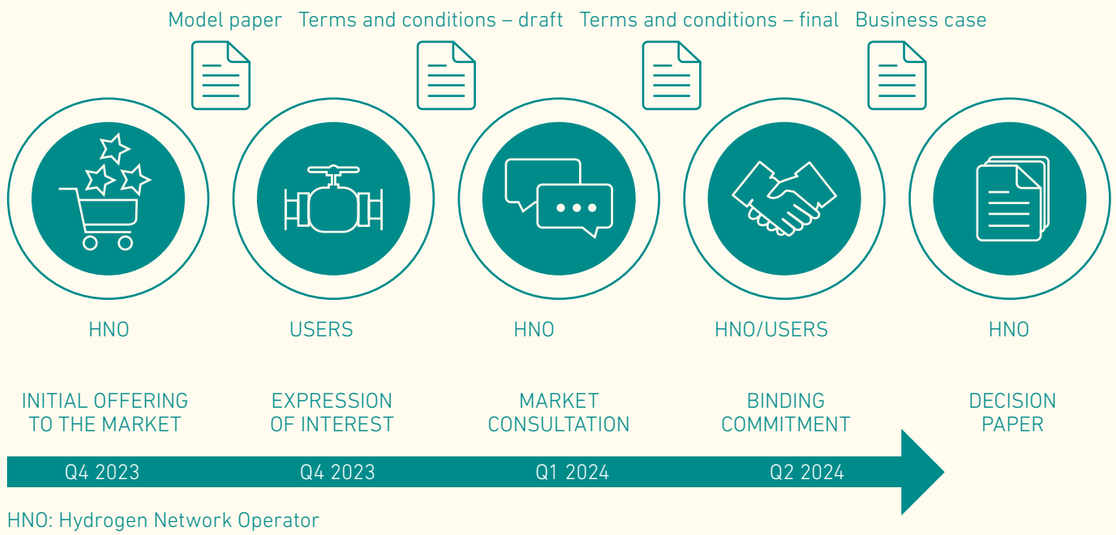


Figure 3 Transport costs calculated at the assumption of a 100% tariff payment relative to the assumed willingness to pay, 2022 DKK prices.

POSSIBLE STEPS TOWARDS BINDING COMMITMENT



HNO: Hydrogen Network Operator

Figure 4 Illustration of a possible process for binding commitments

In the analysis, no limitation related to the operators' willingness to pay for transport has been assumed. This results in an average transport cost of about EUR 8/MWh in the period 2031-2050, a nominal internal rate of return (IRR) of 6.2% and a real payback period of about 17 years. Note that the IRR should be considered in relation to the investment risk profile and the costs of capital, and that a positive IRR is thus not in itself the same thing as a commercially sustainable investment.

Note also that the average transport cost is below the assumed upper willingness-to-pay limit of EUR 9/MWh indicated by the market participants in the market dialogue. However, the annual transport costs are above the assumed upper willingness-to-pay limit during the system start-up phase, mainly due to the expected phase-in of transport volumes over several years and lower volumes in the early years, Figure 3.

The corporate economic analysis assumed that income consists solely of tariffs from users. In the maturation project work continues, on financing the hydrogen infrastructure, as well as the possibilities, necessity, and scope of other sources of income, including a decision on whether to apply for EU funding for an establishment project.

MARKET MODEL FOR HYDROGEN TRANSPORT AND BINDING COMMITMENTS

MARKET MODEL

The market model for hydrogen transport provides the framework for the terms and conditions that will apply to users of the public hydrogen infrastructure. The market model must balance the needs of the market participants, the hydrogen system, and the energy system as a whole; incorporate the relevant national and future European regulations; allow for the fact that the hydrogen market is taking its first steps and will mature over time; and take account of operational, system-related, and technical criteria for the hydrogen system.

The feasibility study addressed four key elements of the market model: 1) payment for the use of the infrastructure, 2) balancing of hydrogen in the hydrogen system, 3) hydrogen quality and 4) connection conditions.

1. Concerning payment for use of the infrastructure, it is proposed to construct a tariff consisting partly of a capacity tariff – with longer-duration capacity products priced lower than short-duration capacity products – and partly of a volume tariff. The aim is to weigh up the infrastructure owner's need for a secure income stream against the need to incentivise flexible production among hydrogen producers in interaction with the electricity market.

2. It is expected that balancing requirements shall make a great deal of flexibility available to the hydrogen market participants, while safeguarding the necessary technical requirements to maintain operations. Requirements for balancing will be defined in a maturation project.

3. Standardisation efforts at European level are establishing a hydrogen quality standard, which Denmark is expected to follow.

4. Conditions for connection to the hydrogen infrastructure are expected to be set out in a connection agreement using principles which are familiar from the natural gas system.

REGULATION

On 1 January 2023, hydrogen was added to the Gas Supply Act (Lov om Gasforsyning). This means that hydrogen and methane (natural gas) are now covered by the same legislation. The amendment, however, gives the Minister for Climate, Energy, and Utilities a mandate to grant exemptions from specific parts of the Gas Supply Act bearing in mind that the hydrogen market and the supporting infrastructure need to be built from nothing. Hydrogen legislation is also being developed at EU level and will eventually be implemented in Danish legislation. The EU legislation aims to deliver a well-functioning internal market for hydrogen in Europe based on established competition law principles learned from the liberalisation of the electricity and gas markets. After 2030, common European market rules will be developed as the hydrogen market matures.

BINDING COMMITMENTS

The purpose of binding commitments is to reduce the risk for hydrogen infrastructure owners and market participants. For the hydrogen infrastructure owner, binding commitments can create some certainty for its revenue base, that market participants will use the infrastructure. For operators, this can ensure that infrastructure is being built and, if capacity contracts are used, operators can secure capacity and sales opportunities.

A process for binding commitments is illustrated in Figure 4. It is essential that more knowledge about user demand and

the willingness to pay is obtained as the process continues. This will support a decision as to how much of the revenue base should be secured via binding commitments as well as which incentives can encourage binding commitments from users. It is also essential that binding commitments are obtained before the completion of a maturation project, as this will help to reduce the risks of the investment decision.

The initial considerations around the market model for hydrogen transport and binding commitments require further maturation in close dialogue with the market participants in the maturation project.

RISKS

As the feasibility study is not binding in nature, the main focus has been to identify general risks in the future phases of a hydrogen infrastructure project. Five general uncertainties/risks were identified.

A. Immature market, uncertainty regarding production, consumption and market. The risk that the outcome of the maturation project does not reflect the actual needs of users.

B. Economic and financial risks. The risk that the corporate and socio-economic aspects do not develop as assumed in the maturation project.

C. Legal risks. The risk that the statutory and legal framework arrives late or is unclear.

D. Limited experience and insufficient knowledge about hydrogen. The risk of insufficient knowledge among employees as well as authorities, business partners and consultants.

E. The risk of inadequate synchronisation with neighbouring system operators.

To a greater or lesser degree, all risks relate to the fact that hydrogen is new to everyone.

More work will be done in the maturation project to further identify risks and to quantify and mitigate them. Especially The corporate economic risks, must be investigated in more detail. As the entire hydrogen market is under construction, a greater risk appetite is expected to be required from all parties in the hydrogen value chain to realize a hydrogen infrastructure.

Figure 5 Preliminary timetable for maturation and establishment phases with phased commissioning in 2028-2030

MATURATION PROJECT

The feasibility study shows that it is necessary to work in two parallel tracks going forward:

1) a maturation project specifically for the hydrogen backbone in Jutland

2) activities to lay the necessary groundwork for integrating hydrogen as a new business area in Energinet, including handling the system responsibility for hydrogen.

The maturation project for a hydrogen pipeline infrastructure will include a socio-economic business case, including maturation of the design of the hydrogen infrastructure and conclusion of binding agreements with market participants. The maturation project will be carried out in close cooperation with Gasunie to ensure simultaneity in the transport of hydrogen to Germany and with Evida in relation to their projects. Internally, the project is coordinated with Gas Storage Denmark regarding hydrogen storage.

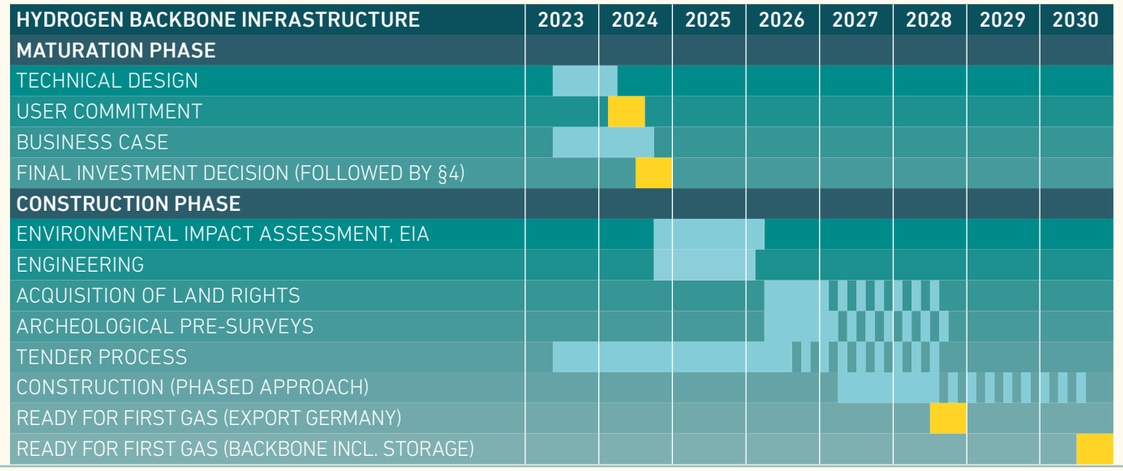
In addition, as mentioned above, the necessary foundation for working with hydrogen must be developed, both to support the maturation project and to handle the system responsibility for hydrogen. Examples of support for the maturation project includes the integration of hydrogen into Energinet's socio-economic model, the design of market frameworks for hydrogen transport, and a financing model. Examples of preparatory system responsibility activities include implementation of regulations and integration of hydrogen into long-term planning.

It is expected that it will be possible to complete the maturation project in 18 months. Before launching it, Energinet must obtain ministerial approval of our maturation application.

For the subsequent establishment project, it is assumed that an investment decision will be made at the end of 2024/early 2025, followed by ministerial approval of the §4 application. The planning and environmental process, which determines when the acquisition of rights and site activities can start, is assumed to be feasible within 18 months, but only if it is prioritised by the relevant government agencies and authorities. Once the project has obtained the necessary planning and environmental permits, it is assumed that the commissioner will be able to immediately start the expropriation process and that preliminary archaeological studies will not produce significant findings that might risk delaying the project. Finally, it is assumed that the construction phase will be completed in phases by qualified construction contractors.

The overall timetable seeks to reflect the political and commercial pressure for a fast pace and is therefore close to being the "critical path".

If the market participants retain their interest in rapid establishment, the maturation project may need to investigate opportunities to bring project activities forward from the establishment phase, e.g., detailed design, the environmental and planning process, and ordering of components with long delivery times.



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