Department for Energy Security & Net Zero

ARUP

Executive Summary

The potential for exporting hydrogen from the UK to continental Europe

Contents

Abbreviations and acronyms

CCS	Carbon Capture and Storage
DESNZ	Department for Energy Security and Net Zero
EU	European Union
IRENA	International Renewable Energy Agency
ktpa	Kilotonnes per annum
LCOH	Levelised Cost of Hydrogen
LCOT	Levelised Cost of Transport
LOHC	Liquid Organic Hydrogen Carrier
LNG	Liquefied Natural Gas
LPG	Liquified Petroleum Gas
Mtpa	Megatonnes per annum
RED	Renewable Energy Directive
RFNBO	Renewable Fuel of Non-Biological Origin
TWh	Terawatt hours

Introduction

The UK Department for Energy Security and Net Zero (DESNZ) commissioned Arup to deliver a study considering the strategic, technical, and economic factors of different transportation methods for hydrogen export from the UK to continental Europe.

The study aimed to build the evidence base on hydrogen export to continental Europe to inform decision making and was split into three main areas:

1. **Setting out the UK opportunity with regards to hydrogen export.**
2. **A pre-feasibility assessment of potential export routes for hydrogen from the UK, considering pipeline and non-pipeline transportation methods.**
3. **A UK-specific levelised cost of transport (LCOT) model.**

The study provided an overview of the perceived benefits and limitations of the potential export routes identified and provides a UK-specific LCOT to outline the UK-specific advantages and disadvantages for hydrogen export to continental Europe.

UK opportunity

The UK is a leader in the development of low-carbon hydrogen production infrastructure. The main objectives of stimulating low-carbon hydrogen production in the UK are to support decarbonisation, enhance the UK's energy security and grow the economy.

Projected demand for low carbon hydrogen in the UK under the net zero 2050 emissions scenarios is significant. A strong pipeline of low carbon hydrogen projects has been established to meet this demand, with projects continuing to be developed and progressed towards final investment decision. This has encouraged policy makers and industry to consider the potential of connecting UK hydrogen infrastructure with continental Europe, in the same way as the natural gas networks are interconnected today, once a thriving hydrogen economy in the UK has been established. An analysis of Europe's hydrogen ambitions at the European Union level and country level was completed to determine whether demand for hydrogen imports in Europe is likely to be sufficient to warrant further work on an export route(s) from the UK. A summary of the results of the analysis, showing the UK's position for hydrogen export to continental Europe, is shown in Table 1.

Table 1: Summary of UK competitiveness for hydrogen export to Europe compared to the other worldwide regions considered.

Scope Area	Potential	Conclusion
UK position for export	Strong	The UK is very well positioned to export low carbon hydrogen to continental Europe. The UK's geographic position means that it can feasibly seek to export hydrogen via pipeline to Europe. A particularly competitive advantage is seen in the shorter pipeline routes, as these minimise the LCOT, however all pipeline routes have a lower LCOT than shipping. Energy security could also be improved by having a hydrogen pipeline connection to and from Europe. There could also be a strategic benefit from becoming an incumbent import route to the EU for hydrogen. Existing gas interconnectors between the UK and Europe have been in operation for many years and expertise from these services is highly applicable to hydrogen export via pipeline. The UK's best competitive position for export to Europe is via pipeline.
Cost competitiveness of UK exports	Promising	The LCOT of pipeline transport is significantly lower than non-pipeline transport at distances up to 2,000 km. Based on publicly available estimates for potential levelised cost of hydrogen production around the world, and the LCOT calculated in this report, the delivered cost of hydrogen landed in Europe from the UK would be competitive with imports of derivatives from regions with lower production costs, when the required product is hydrogen.
Alignment with European importers	Good	The UK is aligned well in terms of hydrogen policy with Belgium, the Netherlands, and Germany who are the primary export targets. A working relationship on gas import/export is already in place with Belgium and the Netherlands. Overall, the UK is better aligned with the EU than other potential major exporters, such as Saudia Arabia, Australia, Chile, Brazil, North African nations and the USA. The UK and the EU have the opportunity to offer improved energy security with a direct pipeline connection to northwest Europe where other major exporters such as North and Latin America, and Australia will only be able to export via ship.

Figure 1: Hydrogen import corridors identified in the EU hydrogen strategy.

To begin with, the infrastructure connecting UK supply with UK demand must be developed. Project Union and other local hydrogen locations have made significant strides towards the development of a UK hydrogen transportation network. The UK Government has agreed, in principle, that there is a need for a core UK hydrogen network, potentially connecting production locations from the south coast to the northeast of Scotland and extending east and west to Norfolk and northwest England.

The appetite for hydrogen imports in Europe is high, the EU set out a target to import 10 million tonnes (approximately 395 TWh higher heating value) of low carbon hydrogen per year by 2030. Three strategic import corridors were identified and prioritised in the EU hydrogen strategy: a North Sea corridor, a Mediterranean corridor and a Ukrainian corridor as shown in Figure 1. Due to the war in Ukraine the North Sea and Mediterranean will be the first to be developed. The UK is positioned well to form part of the North Sea corridor.

Countries in northwest Europe, particularly Belgium, the Netherlands, and Germany are leading the development of low carbon hydrogen infrastructure in continental Europe and have already committed public spending to the development of hydrogen networks, with a focus on imports. Development of hydrogen production, import, transportation, and storage infrastructure in Europe to date has centred around large demand areas in the industrial regions of northwest Germany and the Netherlands, so the UK is well positioned geographically to facilitate a pipeline connection to these import locations.

Currently, national hydrogen strategies of EU members have production targets which may broadly align with the EU domestic production target in 2030. In addition to domestic production, the EU has an import target of 10 Mtpa (395 TWh/yr) of hydrogen by 2030, with trade between EU nations counting towards this import target. The current level of ambition for imports to the EU outstrips all projections on the quantity of low carbon hydrogen that will actually be available for import in the timeframes set out, so it is unlikely that nations with low carbon hydrogen available for export will face significant competition on price. This means that the UK could be in a strong position to export hydrogen to Europe, even if production costs are higher than other regions if it can achieve first mover or fast follower status.

Even if price is considered, analysis completed by the International Renewable Energy Agency (IRENA) has shown that hydrogen production costs in the UK, especially in areas with high renewable potential, could be some of the lowest in Europe[1]. Moreover, given the UK's geographic position, the cost of transporting the hydrogen to Europe will be lower compared to importing from North America, Latin America, or Australia, increasing the competitiveness of UK hydrogen on a delivered cost basis, particularly if hydrogen is exported via pipeline. Considering Levelised Cost of Hydrogen (LCOH) projections from the IRENA and the Levelised Cost of Transport (LCOT) model developed in this report, the UK can be competitive for the export of hydrogen to continental Europe but likely only via pipeline export. Facilitating export solutions also has the potential to improve energy security for both the UK and EU, as we simultaneously drive down emissions in the UK.

The results of this study indicate that hydrogen export from the UK to continental Europe via pipeline presents a significant opportunity for the UK hydrogen economy. The UK's geographic proximity to the major hydrogen demand centres in northwest Europe mean that transport costs will be significantly lower from the UK than other regions with good renewable resources, which, aside from Norway and North Africa, will only be able to export hydrogen to Europe via shipping. However, to unlock any potential opportunity, the export concept requires significant development if the opportunity is to be realised and the integration of production, transport, storage and export strategy.

1 International Renewable Energy Agency. (2022). *Global Hydrogen Trade to Meet the 1.5 C Climate Goal. Part III: Green Hydrogen Cost and Potential.*

Selecting a transport vector

The analysis carried out in this report indicated that large scale export of hydrogen from the UK is likely to only be potentially viable in two main categories, pipeline transport and shipping. To enable a fair comparison of the vectors, the specification of hydrogen entering and leaving the export route was set to the same conditions (gaseous hydrogen at a defined pressure and purity).

Each pipeline and shipping transport vector considered is made up of several different process steps, from conversion and storage on the UK side, then transport, and storage and re-conversion on the European side, as shown in Figure 3. For each vector, at least one element of the transportation chain is still to be demonstrated at scale. Given the constraints and study basis assumptions, new pipelines are preferred for nearly all options of distances and flowrates considered in this study for all timescales.

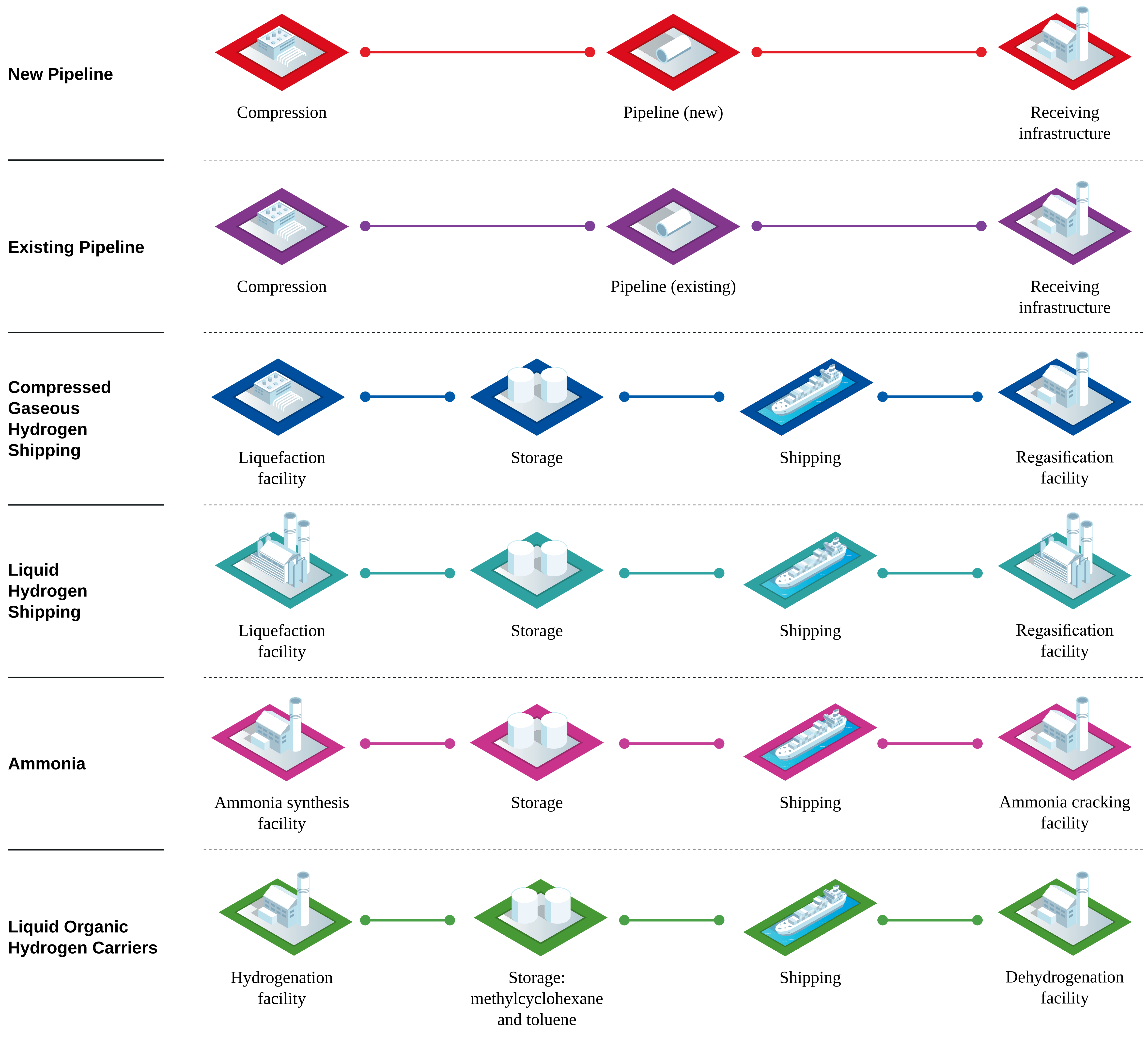


Figure 2: Transport vectors considered in this study.

Pipeline transport

Existing gas interconnectors between the UK and continental Europe were considered as potential export options. However, there is significant uncertainty in the availability of these pipelines for repurposing to hydrogen service, due to existing commitments, energy security requirements and future business cases. Due to the uncertainty in availability, repurposed existing pipelines may not be practical to facilitate the timely development of a hydrogen export route to Europe.

The UK has significant expertise and capability in building and operating gas pipelines and terminals for the international transport of gas. Alongside the existing interconnector gas terminals, there are several other terminals which may be capable of repurposing to support the export of hydrogen. It is expected that the Bacton and Easington terminals could potentially serve as hydrogen export locations while still operating as natural gas import/export terminals if new pipelines were constructed.

The design of new pipelines can be tailored to suit hydrogen operation at specific capacity and pressure specifications which provides improved control over the technical, operational, and health and safety implications of operating high pressure hydrogen pipelines compared to repurposing existing pipelines. New pipelines also enable specific start and end points to be selected based on domestic and European hydrogen infrastructure development, rather than constraining the start and end points to the existing natural gas interconnection points. Construction methods for subsea pipelines are well understood, although there is uncertainty around the availability of lay barges which introduces a schedule and cost risk.

> “Bacton and Easington terminals could potentially serve as hydrogen export locations while still operating the existing natural gas interconnectors, if new hydrogen pipelines were constructed.”

Given the uncertainty around the availability and suitability of existing interconnectors to be repurposed for hydrogen transport, new build pipelines were considered as the base case for LCOT analysis of pipeline vectors.

Shipping

For shipping purposes, the size and type of the required transport fleet depends on the transport vector selected, as the means of transport are at different stages of technological readiness for each vector. For example, liquid organic hydrogen carriers (LOHC) can be transported in conventional oil tankers, and ammonia can be transported in refrigerated chemical tankers. By contrast, liquefied hydrogen will need to be transported in large carriers with a similar design to LNG carriers, and compressed hydrogen will be delivered in tanker ships analogous to those transporting compressed natural gas.

Existing carrier vessels for ammonia and bulk liquids can be directly used for the transport of ammonia and LOHCs, respectively. For compressed and liquid hydrogen transport, the potential capacity of vessels is more uncertain. Based on the research completed in this study, potential future capacities for these vessels were assumed based on projections in the literature and comparison to existing LNG and compressed natural gas carriers, which have similar design conditions to what will be required in new hydrogen carriers. However compressed and liquid hydrogen carriers are at a very early stage of development and there is significant uncertainty around their potential to be competitive large-scale transport options for hydrogen in the future, which is reflected in the LCOT estimates.

To repurpose the existing infrastructure for all non-pipeline transport options, new conversion systems to convert hydrogen to the chosen vector for transport and back to hydrogen at the other end would be required to facilitate export. The conversion systems add significant complexity and cost to shipping export routes. This also means that the timeline for exporting via shipping is dependent on the roll out of conversion infrastructure, which introduces significant uncertainty to the potential timeframe to export.

> “…the timeline for exporting via shipping is dependent on the roll out of conversion infrastructure, which introduces significant uncertainty to the potential timeframe to export.”

Land side facilities required for the conversion and storage of the respective hydrogen vectors were also included in the LCOT assessment as these facilities are complex to design and operate, and energy and capital intensive.

Assessing hydrogen export options

To develop potential export routes, potential export locations were selected considering geographic position, existing infrastructure and facilities, planned UK hydrogen production and transport infrastructure and availability. Likewise, based on planned European infrastructure, potential import locations to be prioritised were identified.

Export routes connecting each of the export locations with import locations were developed to a pre-feasibility level to enable a cost comparison to be developed using a LCOT model. The locations selected offered the best balance of proximity to planned infrastructure, least complex routes, existing export and product handling capabilities, and proximity to European import locations.

1. UK export routes

The UK is well positioned to export hydrogen to Europe via pipeline and provides one of the shortest connection routes from any country outside the EU. There is also the potential to export hydrogen to Europe via ship in derivative form. Global hydrogen trade is in its infancy and the UK is in a strong position to potentially become a key exporter to northwest Europe, which is expected to be one of the largest demand centres for low carbon hydrogen in the world out to 2050.

A key next step of developing an export route is the selection of a suitable export location(s) in the UK. The location selection process will depend on the sequencing of developing a domestic and international network, if a hydrogen export route is progressed. Three scenarios are set out below, which aim to demonstrate how the three factors identified above would be considered differently in the location selection process, dependent on the build out strategy selected.

Scenario 1

An export route from the UK to continental Europe is established before a core UK domestic hydrogen network is fully developed.

Scenario 2

An export route to continental Europe is not considered until the UK's core hydrogen network is fully developed.

Scenario 3

Export routes to continental Europe are considered as part of strategic planning for, and the development of the UK's core network.

Scenario 1 could see an export route developed sooner than either of the other two scenarios, giving the UK hydrogen sector an advantage as first-mover status. This scenario would likely connect electrolytic hydrogen production in the UK directly to demand in continental Europe, due to the renewable fuel from non-biological origin (RFNBO) requirements under the EU Renewable Energy Directive (RED), where a certain percentage of low carbon hydrogen used in industry must qualify as a RFNBO. Accordingly, the selection process would be heavily influenced by the location of electrolytic hydrogen production. However, this could result in higher hydrogen transportations costs, as developing export routes from these locations may be more costly than other, shorter routes.

In Scenario 2, as the UK would have a fully-connected hydrogen network, the preferred UK export location would be selected based on cost of transport. However, the delayed build-out would risk the UK losing first mover status if export routes are considered only after a core domestic hydrogen network is fully established. This may impact the UK's competitive advantage over other countries aiming to export hydrogen to Europe, if export routes from other regions are brought into service before a connection from the UK. Since the development timeline of export infrastructure is significant, if a decision on hydrogen export is delayed until surplus hydrogen production is available, the UK's competitive position in export may also be further affected.

Therefore, it is recommended that the development of a potential export route to Europe is considered as part of the strategic planning for domestic core network (Scenario 3) to mitigate against:

1. The potential cost impacts of establishing an export route solely based on the location of electrolytic hydrogen production as outlined in Scenario 1.
2. The potential schedule impacts of delaying a decision on export routeing until a UK core hydrogen network is established outlined in Scenario 2.

Continuing the development of a potential export route through further studies and engagement with potential importers in Europe would provide the opportunity to gather further evidence and mitigate against the above risks.

"…the UK has extensive infrastructure and expertise relating to the handling, import, and export of bulk liquids such as methanol, which are analogous to the transportation of LOHCs."

2. Existing and planned UK hydrogen infrastructure to support export

Research was completed on existing gas import/export infrastructure, the location of planned UK hydrogen production, transportation and storage infrastructure and port facilities. Data was consolidated into an ArcGIS database to enable spatial representation of the data to be used to support the selection of potential export locations. Information on the potential cost of hydrogen production across the UK taken from the International Energy Agency and IRENA was also reviewed to help inform the selection of potential export locations. The data gathered heavily influenced the selection of potential export locations as good access to hydrogen infrastructure is required to facilitate export.

The UK has significant existing export infrastructure and expertise relating to the import and export of natural gas via pipeline. Much of this infrastructure is likely to have the potential to support the development of a new hydrogen pipeline connection to Europe. This could help to reduce the cost, time to construct and environmental impact of constructing a new pipeline connection to Europe, hence these locations have been prioritised for consideration as export locations.

Available port facilities were also considered in the selection of potential routes. Ports which cater for liquefied natural gas (LNG), liquid petroleum gas (LPG) and methanol were considered as potential strategic areas of development in the supply chain to cater for hydrogen shipping in the future. The list of potential export locations considered for export via shipping include Isle of Grain (Medway), Milford Haven, Teesside, Grangemouth, and Immingham. The UK already stores, imports, and exports ammonia at port facilities spread across the country and imports and stores LNG at three facilities.

Similarly, the UK has extensive infrastructure and expertise relating to the handling, import, and export of bulk liquids such as methanol, which are analogous to the transportation of LOHCs. On the European side, there are several terminals across Europe which have the infrastructure to support the import of LNG, ammonia, and methanol. Each of these European locations has been considered as a potential import location for hydrogen vectors and categorised into the respective derivatives they could handle ammonia, LOHCs, compressed gaseous hydrogen, or liquid hydrogen.

3. Export corridors identification

Export corridors between the UK and continental Europe were identified considering the technical feasibility of the potential corridors. Several factors were considered in the selection of the potential including:

- Existing and planned infrastructure to support hydrogen production, transport, and handling,
- Access to potential demand sources,
- Routeing constraints between export, import and demand locations.

Potential export locations were biased towards the east coast of the UK as the east coast locations have substantial existing infrastructure, good access to planned hydrogen production and transport infrastructure, and access to the shortest crossing routes to infrastructure on the European side. Potential import locations were biased towards countries in northwest Europe, particularly Belgium, the Netherlands, and Germany, primarily due to their geographical proximity to the UK and strong backing for hydrogen imports and infrastructure development, among other factors.

Routes between the potential export and import locations identified were used to inform the cost analysis and present an overview of the technical and cost considerations for exporting from different locations in the UK. Potential import and export locations are shown in Figure 3.

4. Pipeline export routes

New pipeline routes were developed from the potential export locations to the priority import locations identified considering technical, environmental, constructability, cost and consenting constraints. ArcGIS Pro software was used to visualise the constraints data and complete the preliminary routeing assessment. The routes from each potential export location are shown in Figure 4, Figure 5, Figure 6, Figure 7, and Figure 8.

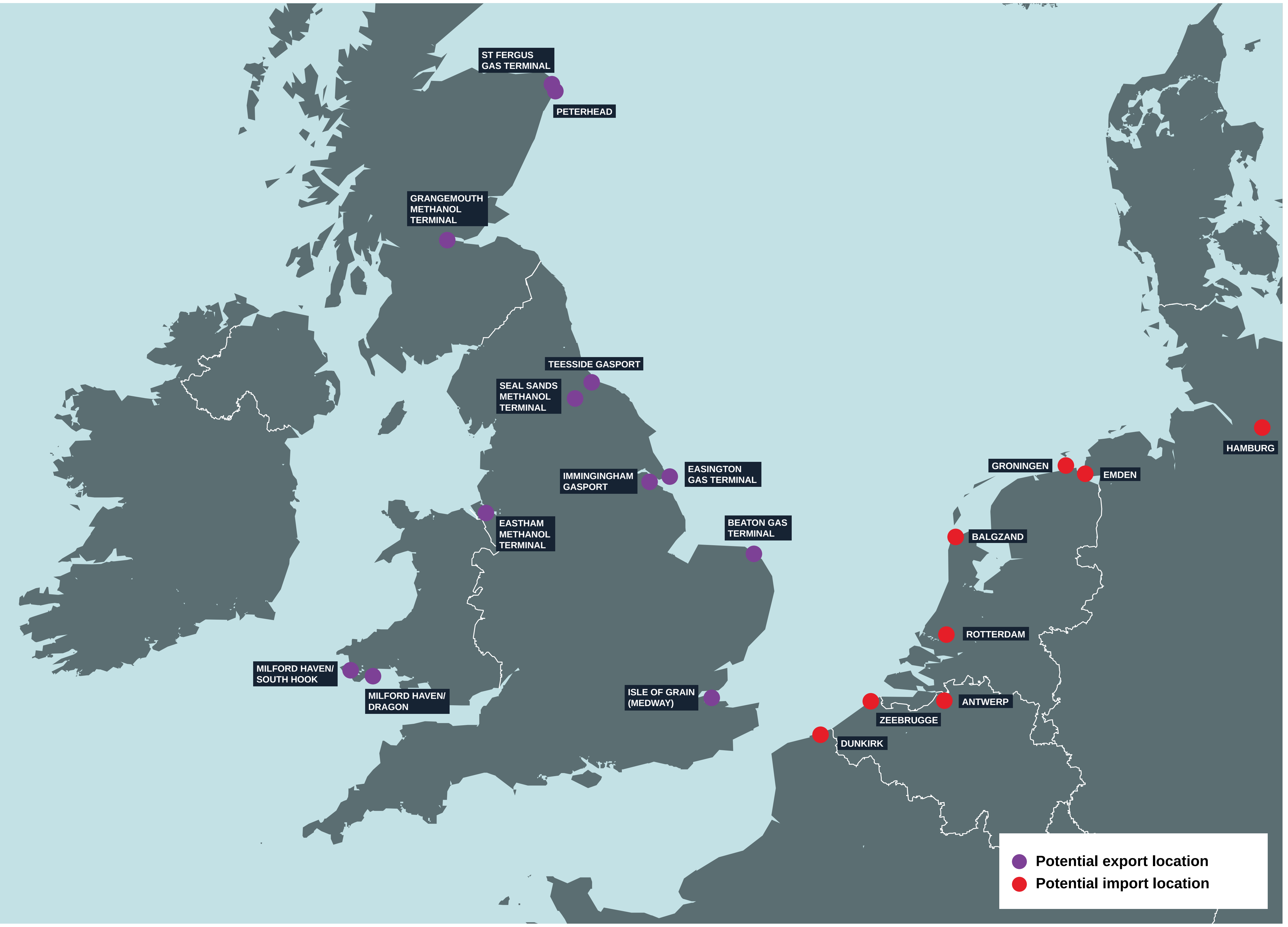
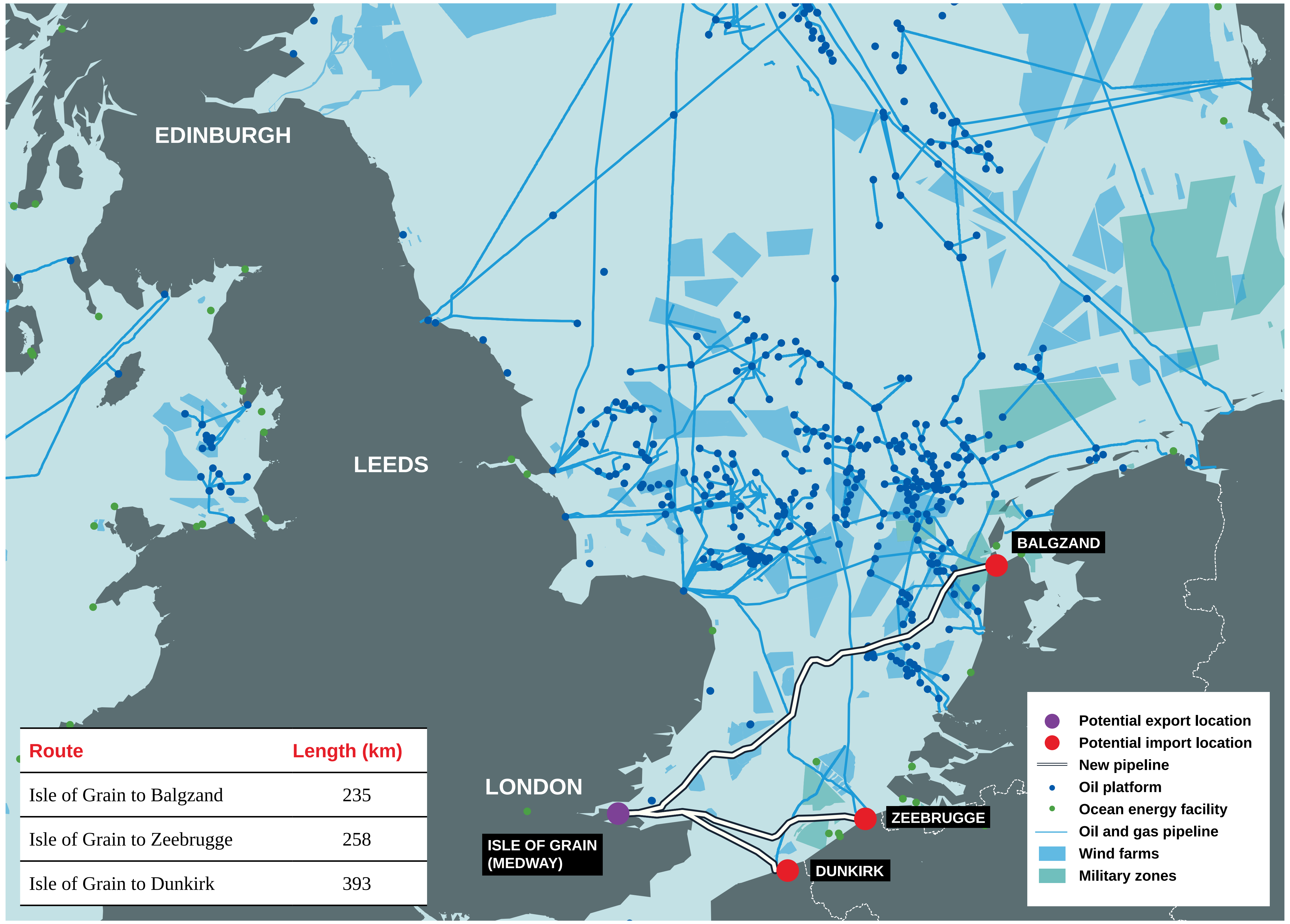
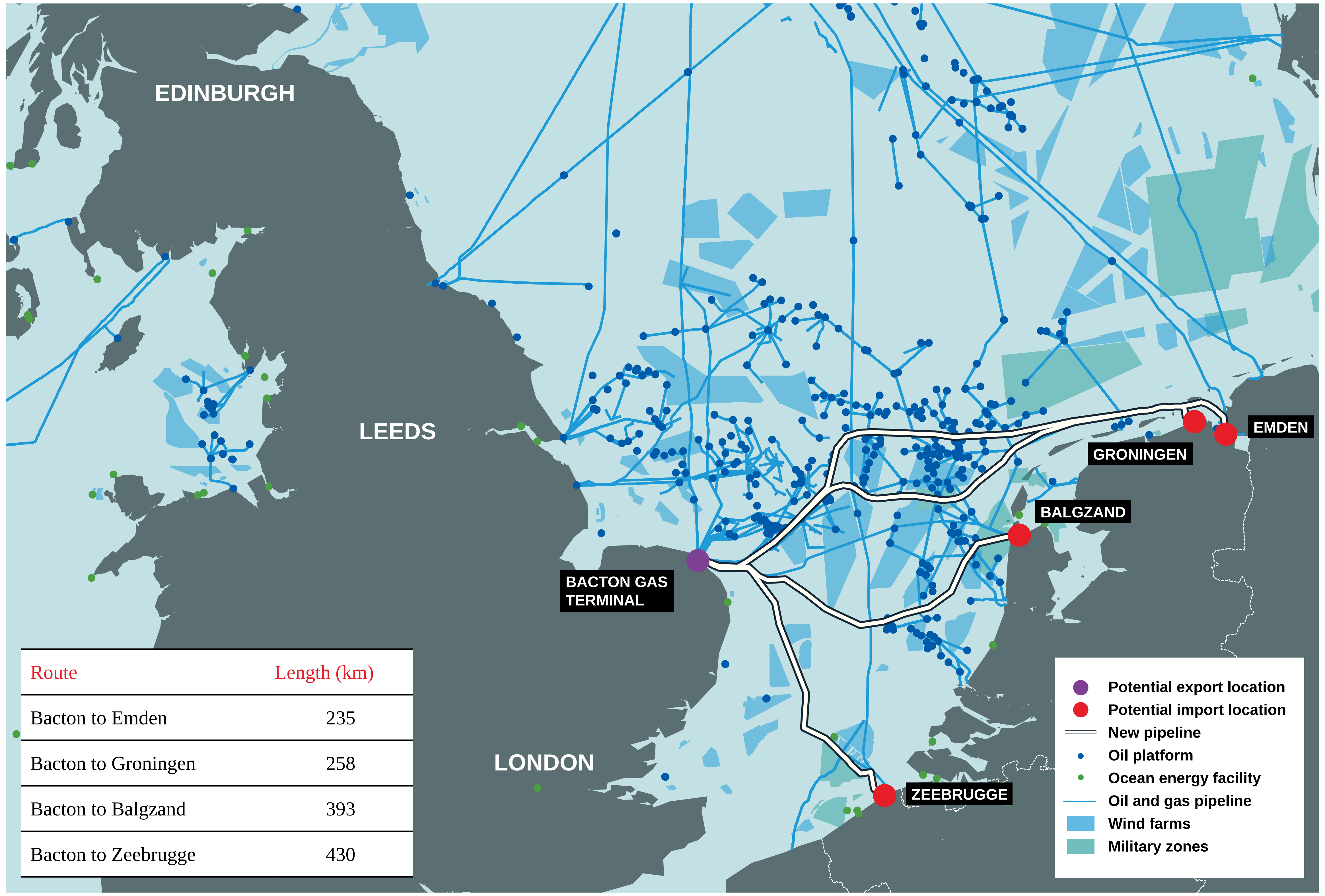


Figure 3: Potential import and export locations identified.



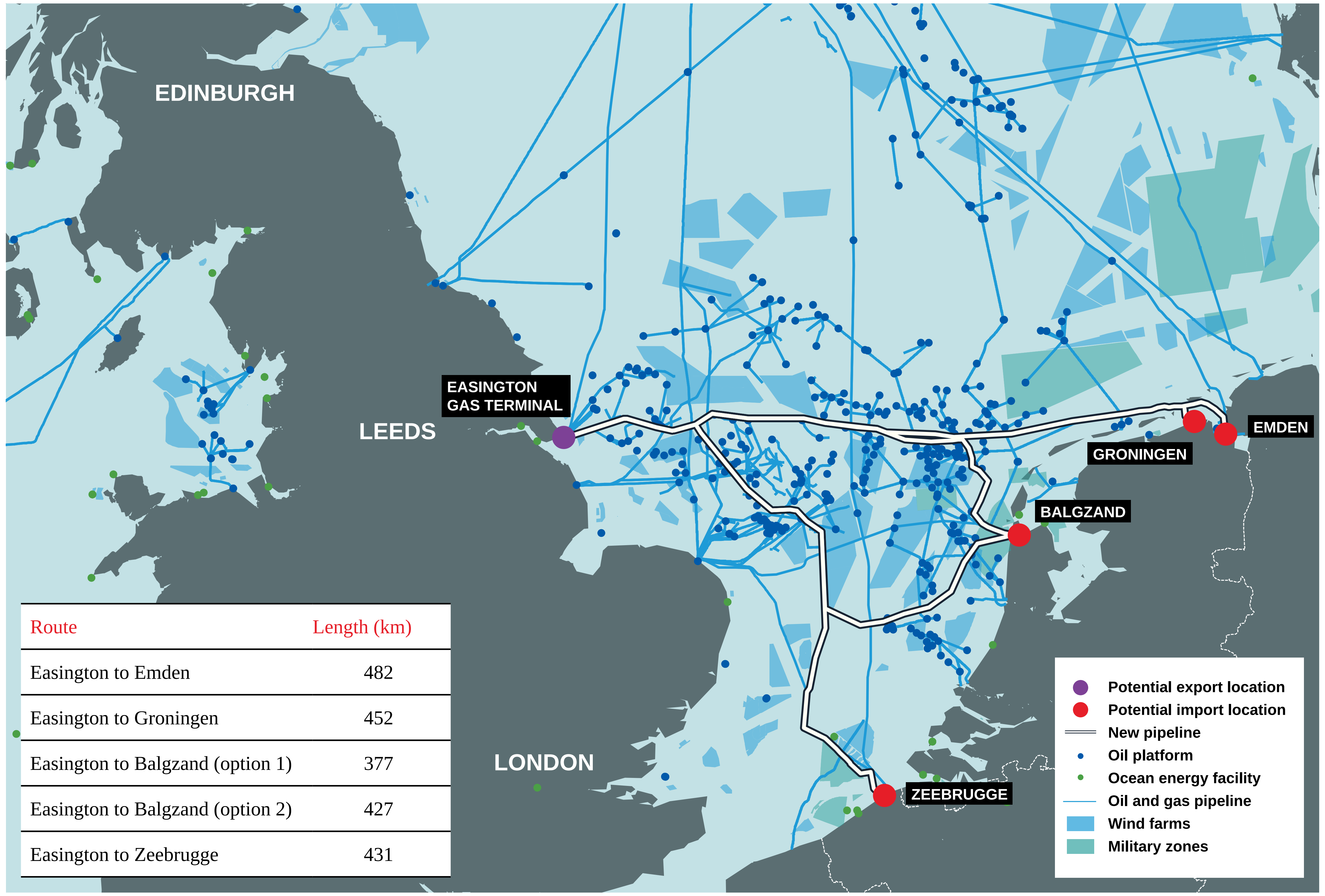
Route	Length (km)
Isle of Grain to Balgzand	235
Isle of Grain to Zeebrugge	258
Isle of Grain to Dunkirk	393

Figure 4: Potential new pipeline routes from the Isle of Grain (Medway) Terminal.



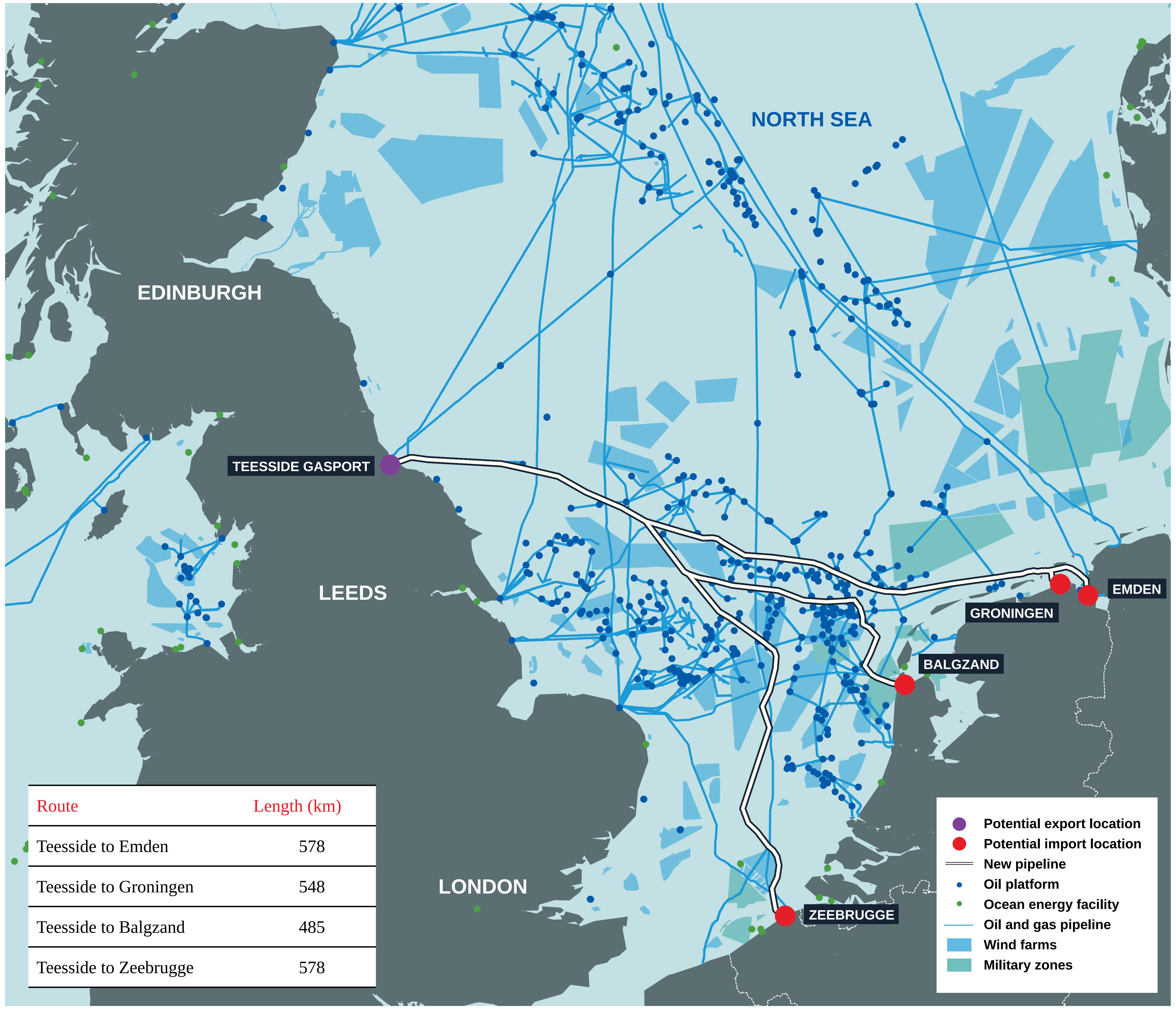
Route	Length (km)
Bacton to Emden	235
Bacton to Groningen	258
Bacton to Balgzand	393
Bacton to Zeebrugge	430

Figure 5: Potential pipeline routeing from Bacton to continental Europe.



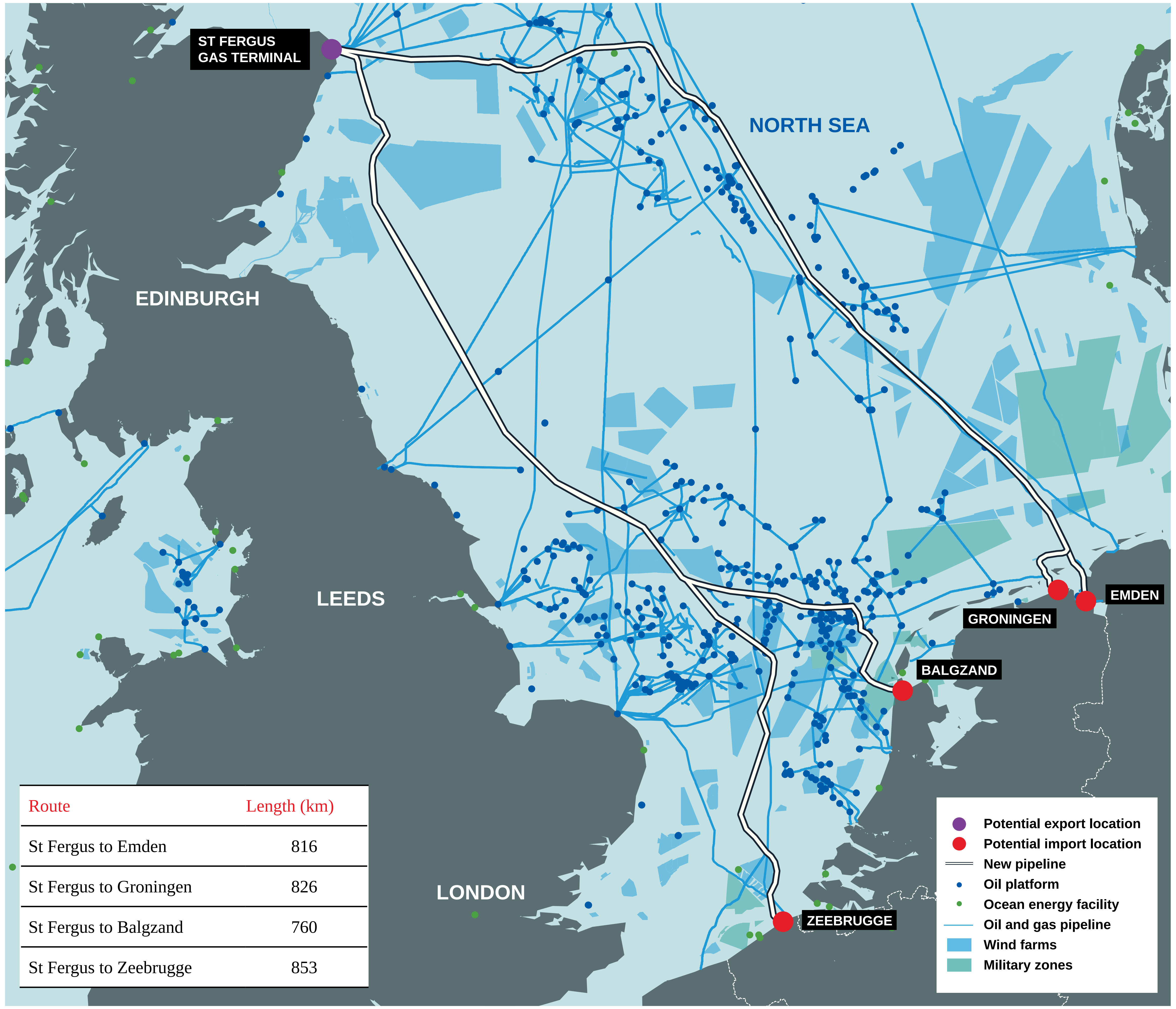
Route	Length (km)
Easington to Emden	482
Easington to Groningen	452
Easington to Balgzand (option 1)	377
Easington to Balgzand (option 2)	427
Easington to Zeebrugge	431

Figure 6: Potential new pipeline routes from Easington.



Route	Length (km)
Teesside to Emden	578
Teesside to Groningen	548
Teesside to Balgzand	485
Teesside to Zeebrugge	578

Figure 7: Potential new pipeline routes from Teesside.



Route	Length (km)
St Fergus to Emden	816
St Fergus to Groningen	826
St Fergus to Balgzand	760
St Fergus to Zeebrugge	853

Figure 8: Potential new pipeline routes from St Fergus.

5. Non-pipeline export routes

Shipping is the only viable non-pipeline transport method for large scale export (>100 ktpa or 3.9 TWh/yr). To facilitate the export of hydrogen and derivatives via shipping, appropriate landside infrastructure is required. Existing landside infrastructure for bulk liquid handling, loading, and export (e.g. methanol) would be suitable for the storage, loading and transportation of LOHCs. Likewise, ammonia is a product which is already traded today, and existing infrastructure would be suitable to export ammonia produced using low carbon hydrogen. While LNG terminals may have potential to be repurposed to liquid hydrogen service, there is significant uncertainty in the technical and economic viability of doing so. Additionally, the LNG terminals have become a key consideration for energy security and hence are unlikely to be available for transition until at least 2040.

Overall, the development of a shipping export route is technically feasible. Landside infrastructure requirements for the storage and loading of ammonia and LOHCs are already deployed today and the requirements for compressed gas storage and handling are analogous to other processes deployed today. Liquid hydrogen is more of an unknown and requires significant technical development in liquefaction processes and vessel design to enable large scale export. Timelines to develop shipping export infrastructure are more uncertain than for pipeline export.

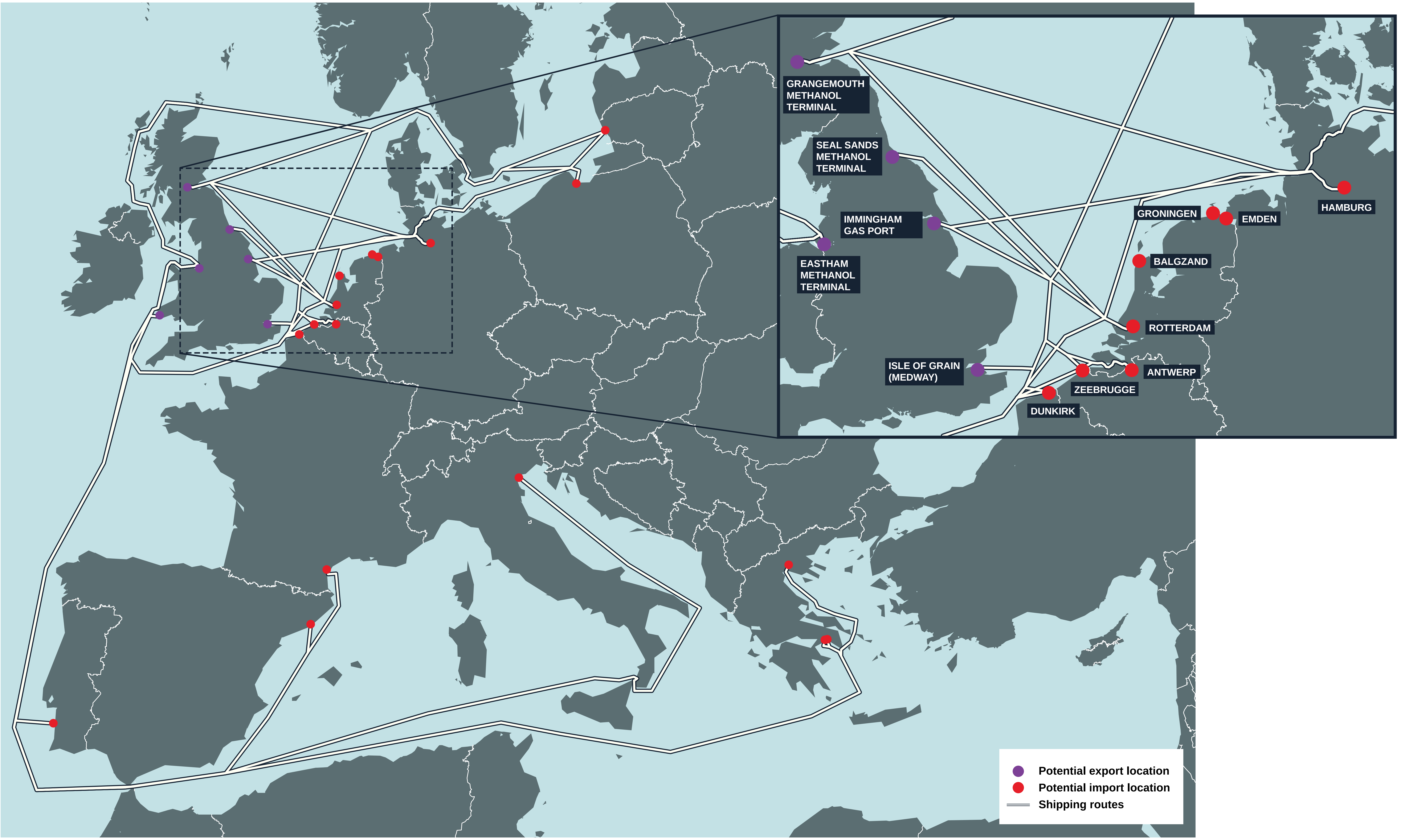


Figure 9: Potential shipping routes for hydrogen derivatives from the UK to continental Europe.

6. Planning, consenting, environmental, and schedule

Planning and consenting are on the critical path for both pipeline and non-pipeline transport options. Planning and consenting timeframes will have a significant impact on the schedule of any export corridor development. The cross-border nature of a pipeline interconnector system introduces additional complexity, however there is significant precedent for the development of these systems in the North Sea to follow.

Environmental issues are prevalent for both pipeline and non-pipeline transport. During design, environmental best practice guidelines from UK and European authorities should be followed to reduce any adverse impact on the environment. Following the design, environmental impact assessments for the new infrastructure would be completed as part of the planning and consenting processes.

Planning, consenting and environmental

For pipelines, the development of a new build pipeline option will require a number of consents and permits to be put in place on both sides of the crossing to comply with national and local legislation. These are numerous and have potentially long consultation and determination periods which must be taken into account in the overall development programme.

Given the UK-EU cross border nature of the project there are likely to be advantages in making an application for the project to be considered a Projects of Mutual Interest (PMI). PMIs are key cross-border energy infrastructure projects between the EU and non-EU countries, which contribute to the energy and climate policy objectives of the Union. This is a new category of projects that can be supported following the revision of the Trans-European Networks for Energy Regulation (TEN-E) in 2022. TEN-E covers cross border permitting to align the consenting regimes in different countries. The PMI Application must be made by a project promoter in an EU Member State. The PMI application process takes around six months although they are subject to application windows.

For shipping, the planning burden could be less impactful than that of constructing a new pipeline. However, the nature of the substances being stored, handled, and shipped as hydrogen derivatives means that compliance with health and safety regulations such as the Control of Major Accident Hazards Regulations (COMAH) 2015 will be required to operate the export facilities in the UK. For European ports, compliance with Seveso III, the European equivalent of the COMAH regulations, will be required for terminals to operate. Like the UK ports, import ports identified for this study are ports which already handle hazardous substances and will therefore already be Seveso compliant where required.

Potential timeframes of developments

The report provides high level estimates for the duration of pipeline and non-pipeline planning, consenting and environmental issues. Figure 10 shows that for both pipeline and shipping export routes, it could take approximately 10 years from FEED commencing until the first start-up and hydrogen is being exported, in an optimistic case. The schedule estimate is based the assumptions used in the study and the Levelised Cost model. Given the level of project maturity there is a high degree of uncertainty over the durations resulting in a wide schedule range. The planning, consenting, and environmental issues heavily influence the development timeframe estimates for the pipeline and non-pipeline export options and introduce uncertainty into schedule estimates and further work is required to improve definition and reduce the uncertainty and these durations are therefore subject to change.

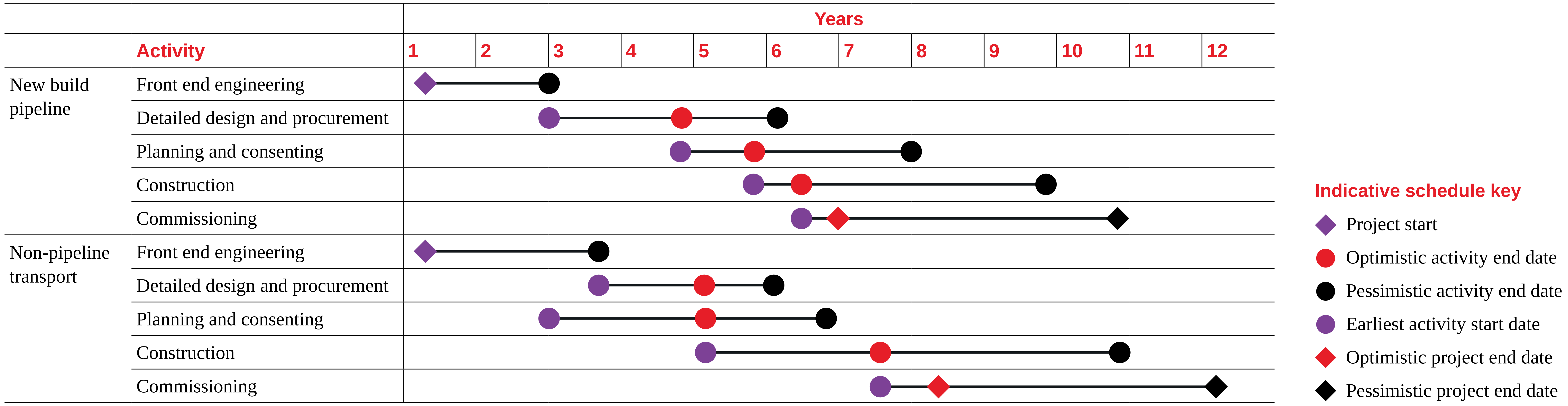


Figure 10: High level indicative project schedules.

Levelised cost of transport

Pipeline export appears to offer an advantage over non-pipeline export for the export of hydrogen from the UK to Europe. When considering pipeline export, the UK has significant existing infrastructure and expertise which could be leveraged to facilitate an export connection.

Potential export locations in the south of the UK offer the shortest, and hence cheapest pipeline export routes but also face complexity in routeing due to interactions with existing infrastructure in the Southern North Sea. Ultimately, all potential export locations could feasibly facilitate the export of hydrogen from the UK to Europe and the overall selection of a preferred location is dependent on strategic, commercial, and political objectives.

The UK's access to renewable resources and short transport distances to northwest Europe mean that UK hydrogen may be cost competitive with hydrogen imports from other worldwide regions in the future due to the lower cost of transport, even if production costs are higher in the UK.

Although some small-scale export via shipping would be possible in a shorter timeframe than pipeline export, the feasibility of shipping hydrogen is dependent on the availability of hydrogen transportation infrastructure (e.g. hydrogenation, hydrogen compression, hydrogen liquefaction facilities) on both the UK and European side. For small volumes, the LCOT would be significantly greater and therefore uncompetitive as a long-term export option. The distance ranges for proposed European destinations from the selected UK export locations are shown in Figure 11 below.

The UK could pipe or ship hydrogen to continental Europe, however the LCOT was found to be significantly lower for pipeline transport compared to shipping for all export locations considered in this study, with locations in the south of the UK (those with the shortest pipeline routes) found to provide the lowest LCOT. The study also showed that shipping costs remain relatively flat over distance therefore, there is less incentive for the UK to ship ammonia or LOHCs short distances to continental Europe as it would be less cost competitive compared to other nations with potentially lower hydrogen production costs exporting derivatives.

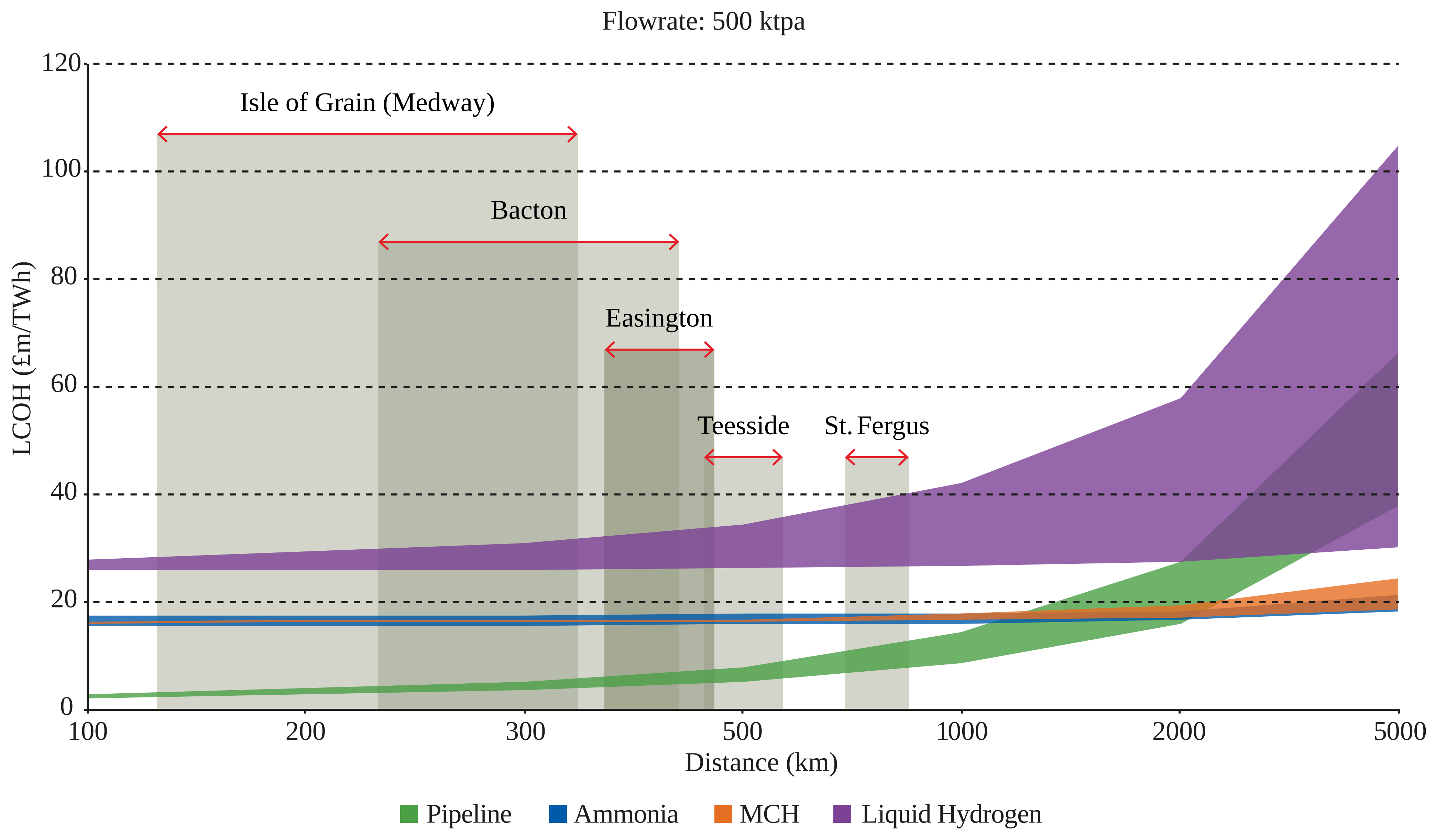


Figure 11: Levelised cost representation with distances from export locations.

Recommended next steps

1.

DESNZ should start considering a pipeline for the export of hydrogen to continental Europe in its strategic planning for UK hydrogen infrastructure to enable further development of estimated tariff rates and to support a potential business case for an export pipeline. Strategies for identifying hydrogen production to be exported should be developed in conjunction with the existing hydrogen production, transportation and storage strategies, domestic industrial decarbonisation targets, carbon budgets, and economic targets to support the development of tariff estimates for an export route, providing a basis for a business case and potentially improve the bankability of the project.

2.

External engagement with counterparts in Belgium, the Netherlands and Germany to collaborate on a potential hydrogen export/import infrastructure project.

3.

Further development of the technical solution for export to minimise the LCOT of a potential pipeline system and narrow down potential export corridor options, considering:

- Further design of the compression systems required for pipeline export, considering synergies with existing infrastructure, to minimise the LCOT of a pipeline export option. Consider whether any existing platforms can be utilised. Further design of the offshore compression facilities in terms of water depth and location in national waters.
- Further work to determine the most appropriate pipeline diameter with respect to the existing flowrate considerations but also future throughput aspirations. The cost of the pipeline does not scale linearly with pipeline diameter therefore, it is usually more appropriate to oversize a pipeline (subject to meeting minimum velocity and pressure drop considerations).
- Further work considering the technological advancements of each derivative production technology (i.e. advancements in green ammonia, hydrogen liquefaction, or LOHC conversion processes). Some cost reduction through market forces or economies of scale could be realised, which were not shown in this study.
- Further development of route corridors to minimise the length of pipeline connections considering the technical, environmental, and regulatory constraints present.
- Evaluation of the technical requirements for connecting into a wider offshore international North Sea hydrogen pipeline network.
- Further consideration of the the development and phasing of hydrogen production, transportation and storage infrastructure in the UK export locations.

4.

Development of an economic case for a potential pipeline export system, considering the cost of investment, potential tariffs to deliver certain rates of return based on the technical design constraints of the pipeline.

5.

Selection of an appropriate export location(s).

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