Contract Number

Client Name:

Project Title:

Project Location:

North Sea Transition Authority

BACTON ENERGY HUB SUPPLY SIG - PHASING

FLUOR®

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Originator:						
Checked:						
Approved:						
Approved by Eng:						
Approved by PM:						

CONTENTS

1. DEFINITIONS AND ABBREVIATIONS

BEH	Bacton Energy Hub
SIG	Special Interest Group

2. REFERENCE DOCUMENTS

The following documents are referenced in this document:

[1] 202220303 Supply PEP Final

[2] Key water-related challenges in the county of Nolfolk Final reort 11/03/2021 Atkins Limited

[3] BEH Infrastructure SIG Core and Build-out Project Layouts

[4] BEH Supply SIG Power Supply Technical Note CTR4

[5] Current and Future Planned Offshore Wind – E and SE England BEH Xodus Infrastructure SIG

3. HOLDS

Hold No:	Section	Description	Status
1	7	Future Natural Gas production rates at the Bacton Facility and availability resources within the NTS	Awaiting study report

4. BACKGROUND

As set out in the Bacton Energy Hub (BEH) vision statement, the overarching goal is to ‘Establish a sustainable hydrogen system to ensure Bacton remains a key regional Energy Hub with a low carbon future‘. The first stage in doing this is to demonstrate that a credible project exists that presents a value-add opportunity worth the investment to take the hub concept forward to execution.

The objective of this phase of the project and the SIGs is to work towards building a foundation on which a credible project can emerge. The basis of this will be the work scopes as set out in each of the SIG TORs. The work scopes will be matured to frame the value proposition and develop a business opportunity document to articulate the potential that the BEH could unlock.

It is recognised that there are a multitude of scenarios that are credible, however detailed scenarios will ultimately be required to be explored by the consortium in the future phases of the project. Therefore, maturing an extensive list of scenarios at this stage of the project will add little value when considering the key objective for this phase. It is NOT the intention of this phase of the project to define the technical specification or detailed basis of design of the hub. But rather propose a development concept supported by a scoping-level design outline to help frame the potential.

The decision has been taken to focus this phase of the project on two key grounding scenarios:

- Core Project: which aims to represent the minimum potential / minimum value proposition of a hydrogen hub at Bacton.
- Build Out: which aims to represent how you would build from the minimum potential to a hub which delivers what we believe is a base analogous with a P50 development case.

The intent of the scenarios as defined below is to provide a framework to help prioritise work scopes and make best use of available resource and time to complete them to a meaningful conclusion. Also, to concentrate activity on areas which deliver on reducing the key uncertainties around the core case and therefore present a basis for the BEH vision that carries a high confidence supporting the credibility of the project to a future consortium.

5. INTRODUCTION AND PURPOSE

The Supply SIG has a number of reportable areas, one of which is the Project Development Phasing. This review presents scenarios for phasing suitable to progress the project. It is recognised that, as the project matures, these scenarios will require revisiting. By no means is this intended to be all encompassing, more a record of discussions and concerns highlighted during the feasibility study.

The development phasing has been composed following discussions regarding viability, layout, engineering considerations and SimOps.

- plot layout
- availability of the wind energy
- green hydrogen
- blue hydrogen
- desalination
- electrical Infrastructure

There are detailed study reports regarding each of the above issued by others within the Supply and Infrastructure SIGs as laid out in Table 6.1 below.

The overarching basis for the above is the work carried out by the Demand SIG tabulated in table 6.1 below, which shows the maximum requirement for hydrogen, far exceeding the currently proposed Supply SIG build out cases.

There are several elements to project phasing which can be considered during this feasibility study, the most significant of these being layout requirements for future build out cases. If the development is constrained to the use of the existing Eni plot, this will ultimately limit the scale of the facilities without the expansion into additional land take.

6. FEED AND PRODUCT BALANCE

The following are the production assumptions which are used as the basis for phasing of production.

		Core Project	Build-out
Demand	Demand Base Assumption	Supply Driven Domestic Only	Balanced supply / demand scenario Domestic Only 70% of current domestic gas demand is met with hydrogen (by 2040)
Demand	Maximum Demand (TWh)	7.9 TWh (2030), 58.2 TWh (2040), 90.3 TWh (2050)	7.9 TWh (2030), 58.2 TWh (2040), 90.3 TWh (2050)
Demand	Maximum Blend %	Assumed 20% blend in 2030 increasing to 100% hydrogen in some parts of region in 2040, all 100% hydrogen in 2050	
Demand	Phasing Description	Assumes blending into NTS by 2030. 2030 demand dominated by blend into NTS/LDZ supply for domestic/commercial; full conversion to 100% hydrogen over time	
Supply	Supply Base Assumption (Blue, Green, Blue + Green)	Blue Only*	Blue + Green
Supply	Blue / Green Phasing Description	1 (or 3 depending on demand at the time) x 355MW SMR/ATR Plant, no additional investment	2030: 3 x 355 MW SMR/ATR plants 2040: 3 x 355 MW SMR/ATR + 2 x 1.8 GW upscaled SMR/ATR + 1 x 2.1 GW Electroliser 2050: 2 x 1.8 GW upscaled SMR/ATR + 1 x 2.1 GW Electroliser + 2 x 2.1 GW Electroliser plants (NB 3 x 355MW SMR/ATR retired)
Supply	Maximum Supply from Blue Hydrogen (TWH / %?)	3 TWh – 100% of demand	9 TWh – 100% of Demand (2030), 39 TWh – 54% of demand (2040) 30 TWh – 33% of demand (2050)

		Core Project	Build-out
Supply	Maximum Supply from Green Hydrogen (TWH / %?)	Zero	0 TWh – 0% of demand (2030) 18 TWh – 46% of demand (2040) 54 TWh – 80% of demand (2050)
Supply	Blue Hydrogen Feedstock Assumptions	Producing and Reserves (Requires approx. 30 mmscf/d). Availability of indigenous supply to be confirmed by SIG	Producing and Reserves + Undeveloped discoveries for Hydrogen with possible import 2040 onwards. Estimated hydrocarbon feedstock: 82 mmscf/d (2030) 356 mmscfd (2040) 274 mmscfd (2050) NB All figures to be verified by SIG, and assessment of indigenous vs imported supply
Supply	Green Hydrogen Feedstock Assumptions	N/A	Redeployment of constrained wind power + connection to (green) grid (2040), Dedicated wind/solar plus connection to (green) grid (2050)
Supply	Export Yes / No?	No	No
Supply	CS Yes / No?	Yes	Yes
Supply	Hydrogen Storage Yes / No?	No	Yes

Table 6.1 [Ref 1]

From the above, process simulations were carried out to approximate the expected feed and product requirements. Note that for the blue hydrogen case although the simulations were based on a specific ATR design the expectation is that the overall balance will not vary significantly from the outcome below.

Feed and Product Balance for Phased Approach for Blue and Electrolyser Hydrogen Production

	Parameter	Unit	2030 Core ATR	2030 Core Electrolyser	2030 Build Out ATR	2030 Build Out Electrolyser
Feed	Power*	MW	355		1065	
		TWh/y	3.1		9.3	
	Demin H_2O for coversion to H2 only	kg/hr	267		802	
		km^3PA	2.3		7.0	
	Natural Gas	kTPA	266		798	
		Nm^3/h	40021		120064	
		MMSCFD	36		108	
	Oxygen	kTPA	284		853	
		Nm^3/h	22706		68118	
Product	Mass Flow H_2	kTPA	79		237	
		kg/hr	9010		27030	
	Mass Flow O_2	kg/hr	-		-	
		kTPA	-		-	
	CO_2 product 95% Capture	kg/hr	645		1936	
		Nm^3/h	37755		113266	

Table 6.2

* Power Demand based on ATR and Electrolyser process only

	Parameter	Unit	2040 Build Out ATR	2040 Build Out Electrolyser	2050 Build Out ATR	2050 Build Out Electrolyser
Feed	Power*	MW	4665	2100	3600	6300
		MWh/y	40893390	18408600	31557600	55225800
		TWh/y	40.9	18.4	31.6	55.2
	Demin H_2O for coversion to H2 only	kmol/hr	194.5	26442.4	150.1	79327.3
		kg/hr	3514	476352	2712	1429056
		km^3PA	30.8	4176	23.8	12527
	Natural Gas	kTPA	3496	-	2698	-
		Nm^3/h	525914	-	405850	-
		MMSCFD	471		364	
	Oxygen	kTPA	3734	-	2882	-
		Nm^3/h	298375	-	230257	-
Product	Mass Flow H_2	T/y	1037903	467223	800954	1401670
		kTPA	1038	467	801	1402
	Molar Flow H_2	kmol/hr	58740	26442	45330	79327
	Molar Flow O_2	kmol/hr	-	13221	-	39664
	Mass Flow O_2	kg/hr	-	423053	-	1269158
		kTPA	-	3708	-	11125
	CO_2 product 95% Capture	kg/hr	8482	-	6546	-
		Nm^3/h	496136	-	382870	-

Table 6.3

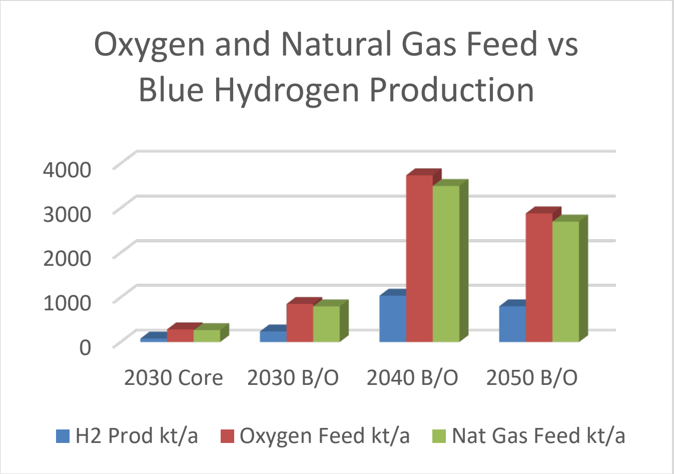


Fig 6.1

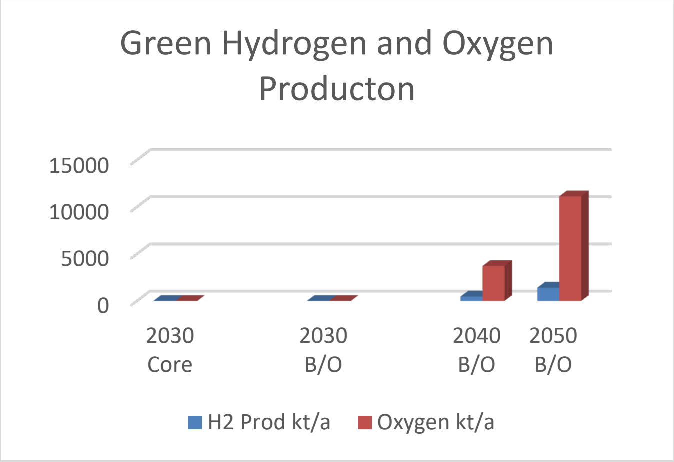


Fig 6.2

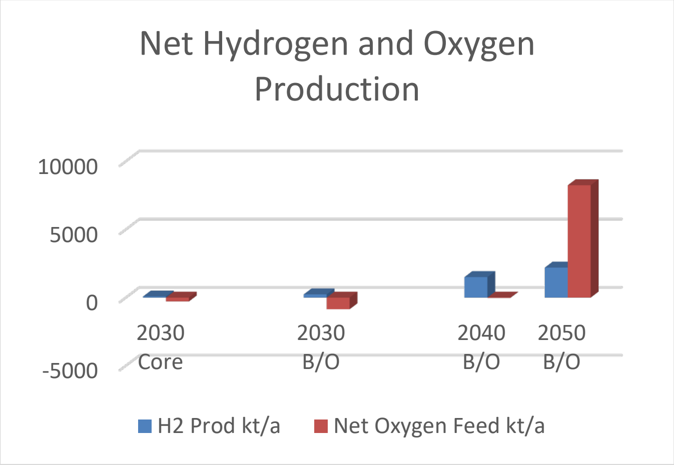


Fig 6.3

7. DISCUSSION

From Table 6.1, the Demand SIG has provided a potential future hydrogen requirement for the East and South East of the UK including London. The Supply SIG has understood these to be in excess of the future potential for the Bacton Energy Hub and provided a Core and aspirational Build-out scenarios for BEH. Bacton Gas Terminal is strategically positioned for hydrogen facilities in the future due to the availability of the gas for creation of blue hydrogen, the Interconnector links to Europe, the potential for vast wind energy supplies and the proximity to a large user in Greater London. SIG phased production levels were produced on this basis.

Layout

The core project plot layout has been provided McDermott. This study has shown that the Core Project could potentially be sited in the existing Bacton area. Footprints were matched against the source data by Supply SIG members in terms of CCS-Enabled H2, electrolytic hydrogen production, power infrastructure and desalination using the existing plot area as a basis. Lay down area for plant construction has been considered but additional space would need to be acquired for the period of construction, this has yet to be determined. Discussion during the SimOps review (section 8 below), indicated that the existing brownfield land (Eni site) has been used over recent years for the dynamic construction phase. Space for construction work is a concern at this site.

The map and plot overlay below show the core project. It is clear that any project Build out case will require additional real estate. Given the novel nature of the blue and green hydrogen technologies "at scale", the plot requirement is expected to evolve and is not considered further here.

Additional plot information is available via the Infrastructure SIG layout scope. Inspecting the plot layout that scope for any of the build out cases will require extension of the Bacton facility fence line. The initial plot layout work shows that the core project appears to fit within the fence line however whether there is appropriate space for the dynamic construction phase. A major concern for any of the build out scope is the requirement for additional land and land permitting requirements. This has not been assessed in the current stage of the BEH feasibility evaluation.

The plot layout was produced by assuming that natural gas for the production of blue hydrogen was available from the National Transmission System, thus eliminating any onus on the owner operators at Bacton. From Table 6.2 and 6.3 above, consideration should be given to the availability of sufficient natural gas to service the requirements for blue hydrogen production (see table 6.2 and 6.3 above). The question of reserves is being addressed by the Supply SIG - Offshore Hydrocarbon Production.

Assessment of the development for the Interconnectors and their future provision is not included as part of the feasibility study. During the study period, the thoughts of all parties involved have probably changed due to the current and future provision of gas from the East.

During discussions regarding the plot layout, the benefits of running a SimOps became apparent. Further details regarding a SimOps review which were held are detailed in Appendix 1.

[ref 3] COURTESY OF MCDERMOTT

Water

It should be noted that there are continued concerns regarding that availability of water for the project as East Anglia is water poor. Ignoring any BEH upgrades to the Bacton Facility

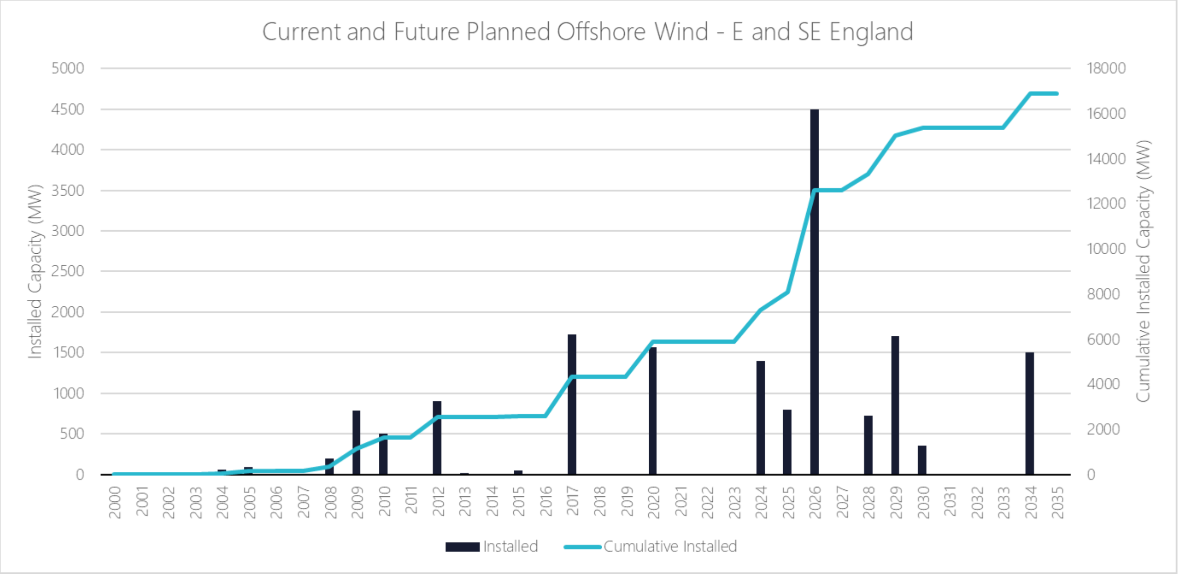
“East Anglia is the driest region in the UK, has the highest forecast growth outside London, is a leading agricultural producer, and has habitats (including wetlands) of international importance. Little surplus water is available; competing demands exist between water needs for public supply, irrigation and the environment. Projections indicate a regional net deficit of around 200 Ml/d by 2050 (WRE, 2020).” [ref 2]

Desalination has been considered for all phases with the exception of the core project. The significance of current and future study cannot be overstated. A combination of the desalination requirements of blue and green hydrogen along with the potential to involve Anglian Water with any future requirements need to be considered in parallel.

Electrical Power

Existing power infrastructure is assumed sufficient for the Core project. The core project benefits from the disinvestment of the Eni site and the relatively small scale of the hydrogen production. For all additional cases significant investment must be made in the electrical infrastructure up to and including the potential requirement for the extension of the Super grid from Norwich to Bacton. Power infrastructure additions and extension was considered during plot development. Significant investment, as yet unquantified, is expected to be required for the electrical upgrades for Build-out cases and will be detailed by the BEH Cost Estimation programme during this feasibility study.

The 2040 and 2050 build out cases have large electrical requirements from the upscaling of blue hydrogen production but much more significantly from electrolytic (green) hydrogen production (2.1GW and 6.3GW respectively for the electrolytic hydrogen production only). One concern is for the availability of sufficient power to provide for the green hydrogen electrical requirements. Information provided by the Instructure SIG quotes offshore wind renewable generation in the East and South East to be in the region of 17GW by 2035 [5]. This is adequate for the BEH expansion programme up to 2040.



COURTESY OF XODUS

It should be noted that electric harmonics due to non-linear loads, such as the electrolyser rectifiers, are identified as an area of uncertainty with the large electrical loads of the 2040 and 2050 build out cases. Power system design will need to carefully consider and optimize the transformer/rectification design, supported with harmonic filters, to reduce the effect of harmonics on the electrical system in these cases.

Natural Gas Feedstock Availability

The availability of the requirement natural gas feedstock for the Core and Build-out cases is being investigated as part of the Supply SIG. The expectation is that there will be sufficient feedstock for the Core project. With reference to Fig 6.1, for the 2040 Build-out cases the expectation is that natural gas will need to be provided by additional resources which may include the provision of new offshore facilities.(HOLD 1)

Summary

There appears to sufficient utilities, raw materials and electrical infrastructure to support the Core Project. Although there is a limited space availability for the dynamic construction process, there appears to be sufficient space for the constructed Core Project.

The aspirational Build-out cases as provided by the BEH Supply SIG are significantly lower than the potential future requirements as laid out by the Demand SIG (See 6.1 [ref 1]). From a layout potential, however, unless there is significant land reallocation at the Bacton Facility, there is not space for any of the Build-out cases. Transport corridors to the site are such that there are logistical limitations for equipment size and there are no docks available at the Bacton facility. The future availability of natural gas is being investigated within the Supply SIG but the expectation is that the future requirement for blue hydrogen will exceed the anticipated production rates (HOLD 1). Although there are plans in place for sufficient power until 2040, the Super grid extension to compensate for this and electrical letdown requirements will require additional currently unavailable space and also are expected to come at significant cost.

8. SIMOPS REVIEW

A SimOps was performed using a cross industry group containing Bacton operations representatives and engineering construction companies.

A given was that although the Eni site is relatively clear, this is a brownfield and no assessment has been made or is available at present to understand the undergrounds systems.

The plot layouts were produced assuming that equipment can be brought to site to production capacity noted in table 1. During the SimOps those located at Bacton highlighted the difficulties with logistics due to the access route constraints which are the only route to the facility. The core project is a mid-scale blue hydrogen production plant and the assumption is that equipment is large but has manageable transportation envelope dimensions for logistics considerations. For the build out cases, however, the scale of the equipment and in particular the carbon capture parts of the process may become factors which require multiple trains of process. This may be the limiting factor to the size of the blue hydrogen processes, without the requirement to upgrade the road system or new docks being developed.

A premise to the SimOps was that to achieve execution of the Core Project and Build-Out, the BEH development will require extensive assessment (Safety, Planning, Engineering, Construction) of the existing facilities and associated interfaces, optimization of plant and processes, determination of execution methodology and must seek and obtain significant Planning Consents. A key element will be simultaneous construction and existing plant operations. The number of construction personnel on site will be dictated by the execution methodology. Pure stick build might mean too many personnel on site driving offsite prefabrication with module build elsewhere and transport of modules by ship or trucks. This aspect should be addressed early as due to the crowded nature of the plot, this is anticipated to be a concern. Laydown area is also another area which should be considered for construction and a formal Strategic Execution Analysis is highly recommended as that will inform the ultimate production capacity within site constraints.

Early on during the SimOps review it became clear that the most beneficial use of time would be to review the core project within which is contained for the most part within the existing plot. This was discussed and agreed with all attendees. See appendix 1 for SimOps Review Output.

9. APPENDICES

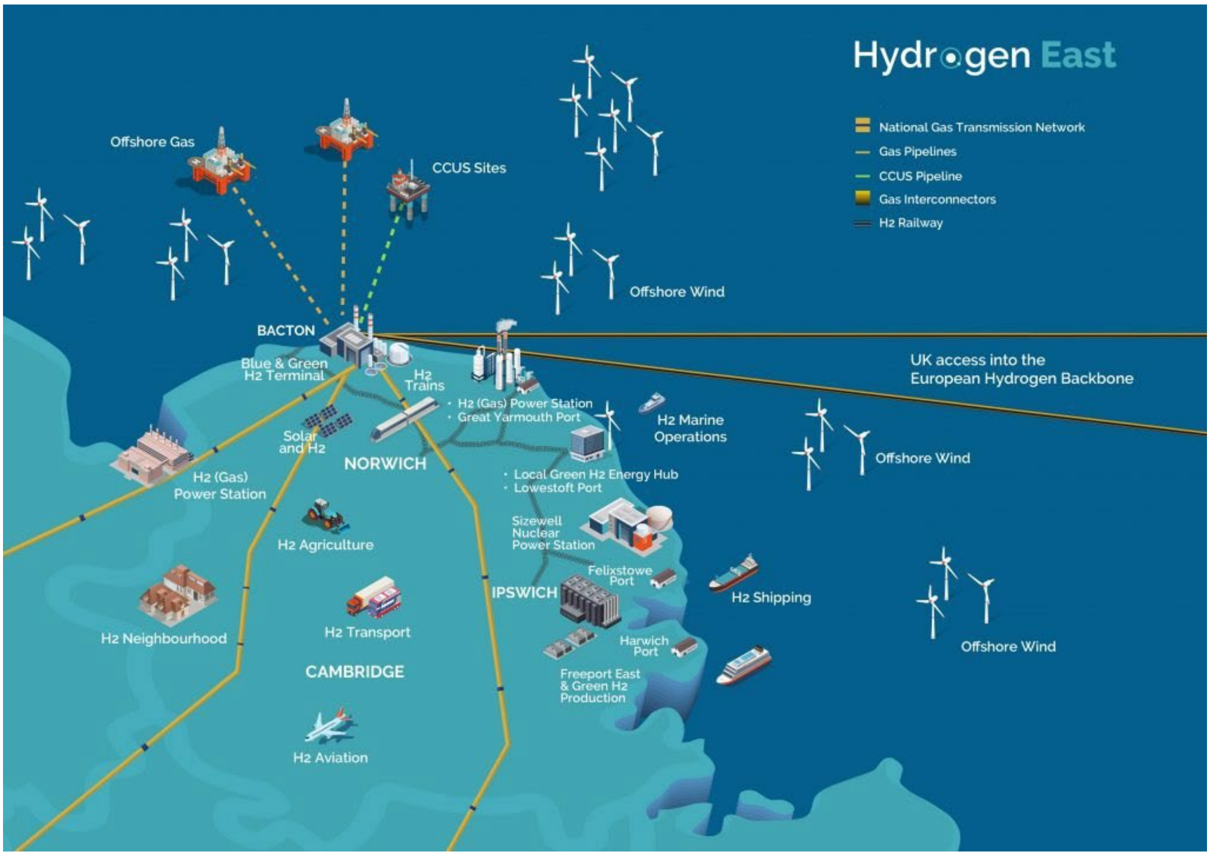
APPENDIX 1: SIMOPS REVIEW

Energy Hub - Supply SIG
Simultaneous Operations (SIMOPS) REVIEW

1. INTRODUCTION

Bacton Energy Hub (text taken from Hydrogen east website)
Hydrogen East was formed in July 2020 to carry out research into the new hydrogen markets and build awareness of new opportunities within the East of England. With the adoption of the 2050 Net Zero target in June 2019, our mission is predicated on the belief that reaching the target in a timely manner is only possible if hydrogen can play a supporting role to rapid electrification of the energy system and can share the heavy lifting in supporting decarbonisation of the heating and transport sectors.

Bacton and the surrounding region offer significant opportunity for hydrogen development, including scope for a cross-cutting energy hub that can play a major role in supporting both the region's aspiration to become the UK's Clean Growth Region and the energy transition needed to deliver the 2050 Net Zero target.
There is a significant market opportunity given the access to a range of low-carbon energy technologies and assets, the need to decarbonise gas supply and the requirement to ensure optimisation of renewables and nuclear production (including heat).
The core components of development of a Bacton Energy Hub include the re-use of North Sea assets for carbon storage, blue and green hydrogen production and strong collaboration with offshore wind and potentially nuclear sectors. This could be supplemented by other asset types, including battery storage, solar, wave or tidal generation, and could see innovative offshore hybrid solutions as well as land-based developments.



Bacton Energy Hub Facilitated Pathway

High level conceptual design work looking into the development options to enable Hydrogen East's vision to be realised is underway. As part of this work the need for a SIMOPs study has been identified.

The SIMOPs review was carried out in a virtual meeting using MS Teams on 12th July 2022 commencing at 9:00 hours.

The purpose of this document is to present the findings / notes from the review.

2. ABBREVIATIONS

H2	Hydrogen
HSE	Health Safety and Environmental
PFD	Process Flow Diagram
SIMOPs	Simultaneous Operations

3. Team Members

The members of the team for the review were:

Name	Company
Andrew Thomas	McDermott
Caterina Spadea	Eni
Daniel Patterson	Exodus
David Tutill	Perenco
Dominic Wright	Saipem
Eric Maina	McDermott
Helen Coleman	Genesis Energies
Ian Wallis	Fluor
Jack Walden	Progressive Energy
John Kennedy	McDermott
Nabeel Kubba	Saipem
Paul Lafferty	Summit-evolution
Ray Kirby	Shell
Samantha Nicholson	Fluor

4. Recording

The review was recorded on an electronic worksheet (attached as Appendix 1).

5. Information Available

The following information was used during the review:

- Preliminary Layouts of the proposed plant development options
- High Level Design options

ATTACHMENT 1
SIMOPS Review Worksheet

Bacton Energy Hub SIMOPs - Core scope 12 July 2022

Number	Issue	Cause	Hazard	Safeguards/ Mitigations	Further work
1	Gas Release	Blowdown on Gas Plant (e.g. Perenco)	Potential for Gas Cloud to drift across the site, leading to fire and or explosion if ignited	Hazardous Area Classification, control of ignition sources. Covered in existing sites' COMAH reports	
2	Upset on Hydrogen Plant	Hydrogen Flaring on Core Project	Potential for ignition of blowdown vent or propane vent if happening concurrently	Analysis of flaring cases and dispersion modelling	Investigate need for/ access to integrated ESD systems
3	Personnel Evacuation	Increased Numbers on site	Red Alert Muster becomes difficult to handle	Envisaged Numbers no greater than previously on site	
4	Domino Events	Major Incident on any of the sites	Escalation to other sites /Domino events	Red Alert System in place. Communication / Interface Management. Bacton Terminal Operators System - runs Emergency Drills	Integration of Site Emergency Response Plans
5	Construction	Construction activities on one of the sites	Potential Impact of Construction traffic on other sites Impact on local populations	Notification of adjacent sites / Traffic Management	
6	Public Opinion	Construction activities	Protests / Objections / damage to relationship with Local Communities	Consultation with local population / Management of public interface / public relations	

Bacton Energy Hub SIMOPs - Core scope 12 July 2022

Number	Issue	Cause	Hazard	Safeguards/ Mitigations	Further work
7	Noise	Blowdown or other unscheduled noisy activities	High Noise levels offsite leading to complaints	Public Engagement / consultation	
8	Electrical Interference	Electrolyser operation	Electromagnetic Radiation leading to potential interference with communication Links to unmanned offshore platforms, causing control issues.	Design Development	Electrical interference studies to be carried out
9	Routing of pipeline	New pipelines	Interference of existing pipelines with proposed routings	Potential to reuse existing pipelines for offshore C02 injection into depleted gas reservoirs.	Beach / pipeline survey required to assess potential routes
10	Construction activities	Limited space	Lack of space for Laydown		Identification of Laydown areas and contractors access
11	Existing Service	Excavation / In ground activities at Eni site	Potential to impact and damage existing live infrastructure crossing the site leading to gas /condensate release, and consequent fire/explosion incident if ignited	Site survey and ground investigation prior to excavation	

Bacton Energy Hub SIMOPs - Core scope 12 July 2022

Number	Issue	Cause	Hazard	Safeguards/ Mitigations	Further work
12	Electrical	Increased Electrical Load	Increased frequency of power outage/ lack of reliability of supply		Power study and new Feeders
13	Transport	Limitations on size envelope that can be transported along local roads	Potentially unable to transport / install large equipment in one piece	Existing transport Studies from install/removal of large vessels	Consultation with existing site operators to leverage experience of transporting large / difficult loads
14		Simultaneous project delivery by multiple contractors/designers	Multiple Systems of work in use on adjacent sites		Develop integrated systems of work
15	Competency	Future Project Timescales	Potential for loss of local experience / knowledge / skill gaps		