HyNet CCUS Pre-FEED

Key Knowledge Deliverable

WP4: CO_2 Road/Rail Transport Final Study Report

HyNet North West

EXECUTIVE SUMMARY

The CO_2 Road/Rail Transport Study Report was generated as part of the Preliminary Front End Engineering and Design (pre-FEED) study for the HyNet Industrial CCUS Project. The HyNet CCUS pre-FEED project commenced in April 2019, and was funded under grant by the Department for Business, Energy and Industrial Strategy (BEIS) under the Carbon Capture Utilisation and Storage (CCUS) Innovation Programme.

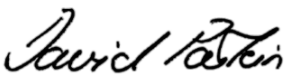
Delivery of the project was through a consortium formed between Progressive Energy Limited, Essar Oil (UK) Limited, CF Fertilisers UK Limited, Peel L&P Environmental, University of Chester, and Cadent Gas Limited.

The main project objectives are as follows;

- To determine the technical feasibility of a full chain Industrial CCUS scheme comprising anchor loads from Stanlow Refinery and Ince Fertiliser Plant and storage in Liverpool Bay fields.
- To determine the optimised trade-off position between lowest initial cost and future scheme growth
- To determine capital and operating costs for the project to +/- 30% to support HMG development of a policy framework and support mechanism
- To undertake environmental scoping and determine a programme of work for the consent process

This document is one of a series of Key Knowledge Deliverables (KKD's) to be issued by BEIS for public information, as follows;

- HyNet CCUS Pre-FEED KKD WP1 - Basis of Design
- HyNet CCUS Pre-FEED KKD WP1 - Final Report
- HyNet CCUS Pre-FEED KKD WP2 - Essar Refinery Concept Study Report
- HyNet CCUS Pre-FEED KKD WP2 - Hydrogen Production Plant
- HyNet CCUS Pre-FEED KKD WP3 - Fertiliser Capture Report
- HyNet CCUS Pre-FEED KKD WP4 - Onshore CO2 Pipeline Design Study Report
- HyNet CCUS Pre-FEED KKD WP4 - CO2 Road Rail Transport Study Report
- HyNet CCUS Pre-FEED KKD WP5 - Flow Assurance Report
- HyNet CCUS Pre-FEED KKD WP6 - Offshore Transport and Storage
- HyNet CCUS Pre-FEED KKD WP7 - Consenting and Land Strategy



Dave Parkin
HyNet Project Director

Hynet Road Rail CO_2 Transport Feasibility Study

CO2 Transport Final Study Report

Progressive Energy Ltd (PEL)

23th December 2019

For Client Issue

Notice

This document contains the expression of the professional opinion of SNC-Lavalin as to the matters set out herein, using its professional judgment and reasonable care. It is to be read in the context of the agreement dated 5th June 2019 (the "Agreement") between Atkins Limited (member of the SNC-Lavalin group) and Progressive Energy Limited (PEL, the "Client"), and the methodology, procedures and techniques used, SNC-Lavalin's assumptions, and the circumstances and constrains under which its mandate was performed. This document is written solely for the purpose stated in the Agreement, and for the sole and exclusive benefit of the Client, whose remedies are limited to those set out in the Agreement. This document is meant to be read as a whole, and sections or parts thereof should thus not be read or relied upon out of context.

SNC-Lavalin has, in preparing the cost estimates, followed methodology and procedures, and exercised due care consistent with the intended level of accuracy, using its professional judgment and reasonable care, and is thus of the opinion that there is a high probability that actual costs will fall within the specified error margin. However, no warranty should be implied as to the accuracy of estimates. Unless expressly stated otherwise, assumptions, data and information supplied by, or gathered from other sources (including the Client, other consultants, testing laboratories and equipment suppliers, etc.) upon which SNC-Lavalin's opinion as set out herein is based has not been verified by SNC-Lavalin; SNC-Lavalin makes no representation as to its accuracy and disclaims all liability with respect thereto.

This document has 44 pages including the cover.

Document history

Revision	Purpose description	Origin-ated	Checked	Reviewed	Author-ised	Date
P01	For internal review	EM, MS, TM	KN, PS	MW	MC	19/12/2019
A01	Final issue to client	EM	TM	MW	MC	23/12/2019

Client signoff

Client	Progressive Energy Ltd (PEL)
Project	HyNet CO2 transport study
Job number	5189899

Contents

Tables

Figures

Definitions

CLIENT: Progressive Energy Limited

SNC-Lavalin: SNC-Lavalin shall include SNC-Lavalin, Atkins, Kentz, and other group companies.

AGREEMENT: Agreement dated 5th June 2019 between SNC-Lavalin and Progressive Energy Ltd. (PEL)

Glossary

Term	Definition
ADR	The European Agreement concerning the International Carriage of Dangerous Goods by Road
Ar	Argon
BoD	Basis of Design
BoE	Basis of Estimate
BFD	Block Flow Diagram
BL	Battery Limit
CH_4	Methane
CO_2	Carbon Dioxide
CCUS	Carbon Capture and utilisation
FEED	Front end engineering design
FOC	Freight operating company
H_2	Hydrogen
H_2O	Water
HSSE	Health Safety Security Environment
ISO	International Organisation for Standardisation
N_2	Nitrogen
NR	National Rail
L	Litres
PEL	Progressive Energy Ltd
POA	Point of Ayr
RAG	Red Amber Green
RID	Regulation concerning the International Carriage of Dangerous Goods by Rail
SR	Stanlow Refinery
t	tons
TEG	Tetraethylene Glycol Unit

1. Introduction

1.1. Background

HyNet is a project conceived and supported by numerous stakeholders, including the partners in this project, to decarbonise heat, power and transport in the North West industrial cluster. The project produces hydrogen from natural gas feedstock using a reforming process, captures and stores the resultant carbon dioxide (CO_2) offshore, and transports the hydrogen to industrial consumers using a new build pipeline with additional blending of hydrogen with natural gas for domestic consumers.

The initial project feasibility study was published in 2017, and a subsequent follow-up report was issued in 2018 (www.hynet.co.uk). As government policies on Carbon Capture Utilisation and Storage (CCUS) and hydrogen deployment are still being formulated, consideration has been given to the approach of focusing on a subset of the proposed HyNet project in the first instance, which provides material industrial emissions reduction, creates expandable CCUS infrastructure and is no regrets in terms of Government commitment.

Phase one of the HyNet project is to develop Industrial CCUS. This phase will capture existing emissions from Stanlow Refinery (Essar) & CF Fertilisers Ltd, Ince, and, using principally existing, repurposed infrastructure, transport the carbon dioxide offshore and store it in the depleted Liverpool Bay fields.

The CCUS concept is to deploy a new CO_2 pipeline (shown as solid orange line in Figure 1-1) connecting the industrial users to a repurposed natural gas pipeline starting at Connah's Quay, which will supply CO_2 to offshore storage.

For the full chain pre-FEED basis of design please refer to Progressive Energy BoD doc, version 1, May 2019 [1]. This counterfactual study was undertaken by SNC-Lavalin to explore the use of road or rail transportation as an alternative to a fixed pipeline (shown as dashed orange line in Figure 1-1).

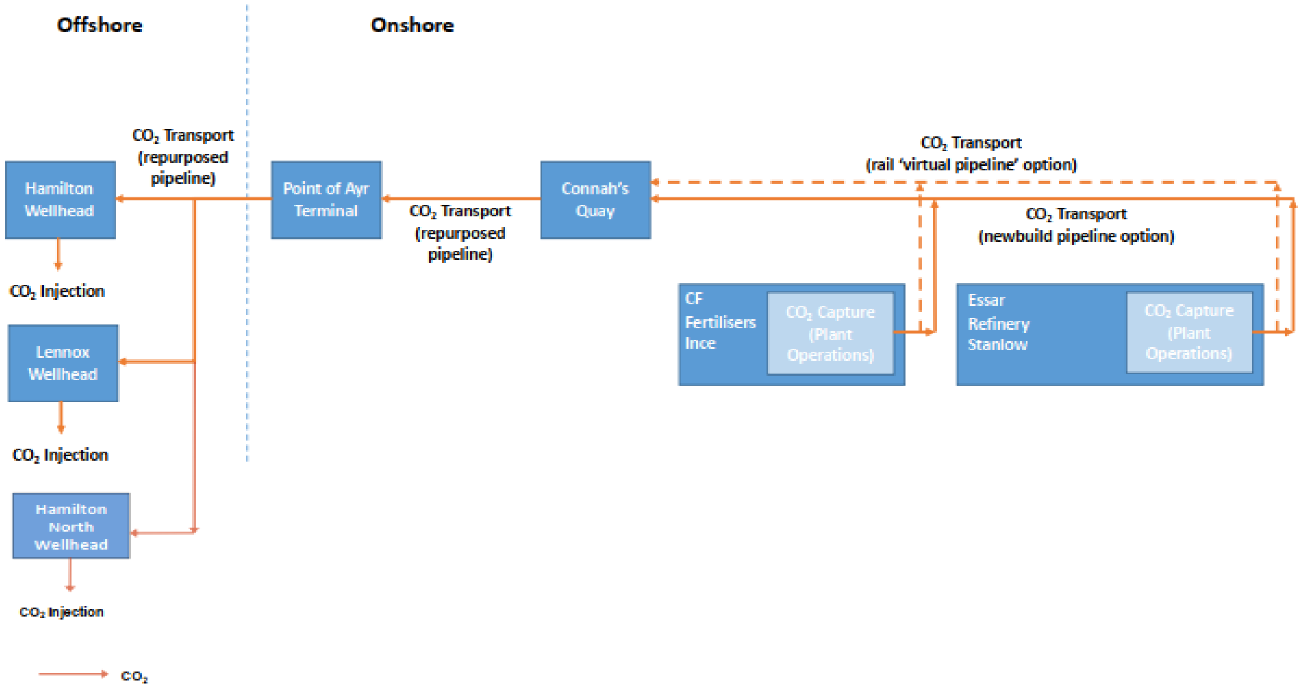


Figure 1-1 – HyNet Phase 1 Project Schematic

1.2. Purpose

The purpose of this final study report (5189899-PM-REP-013) is to summarise and consolidate the feasibility study findings. The study investigated the available road and rail CO_2 transport options within the study battery limits (see optioneering study report, 5189899-PM-REP-007, [2]). The site options reviewed were down selected against an agreed selection criteria basis (including: Technical feasibility, CapEx, Reliability, Safety and carbon accountancy).

The Essar Rail option, at Stanlow refinery, was selected to be the focus of the final report and cost estimate.

1.3. Scope

This study report details the Process & Transport/Civil requirements at the CO_2 production source (Stanlow Refinery) and CO_2 unloading point, at Point of Ayr (POA). This final report details the proposed operational philosophy, including filling/emptying arrangements of selected ISO tanks. The requirement for buffer CO_2 storage at CO_2 production source and regasification unloading site is also detailed and shown indicatively against the overall footprint requirements.

This final study report addresses the outline project objectives, defined at the project kick off meeting (Ref. [3]):

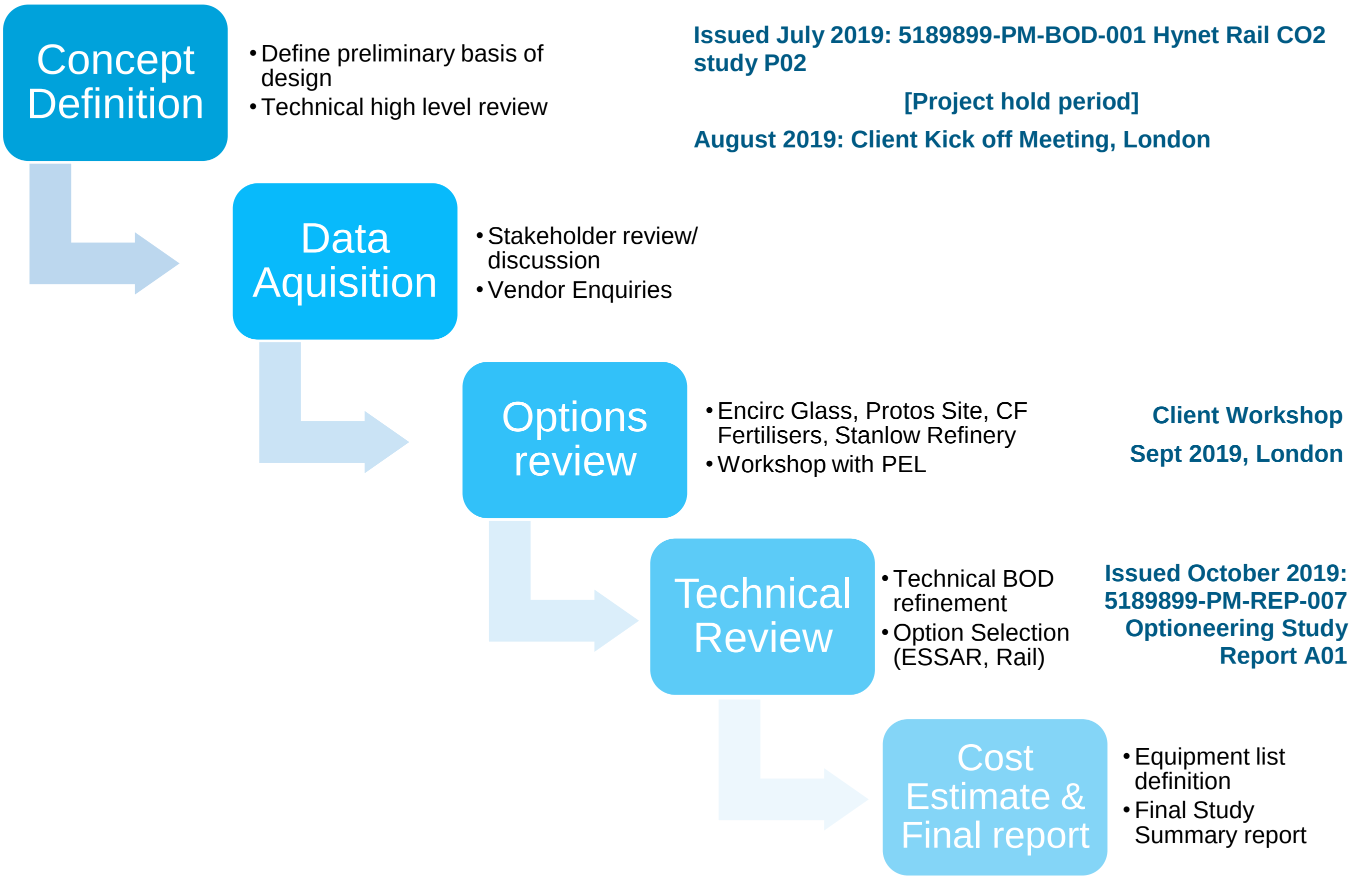
- To demonstrate technical feasibility (1.2 $MtCO_2$/yr CO_2 by ISO containers via rail transport)
- Determine total project costs (CapEx); which may inform lifetime of project.
- Undertake a qualitative comparative risk (HSSE) assessment.

1.4. Responsibility

Stakeholder	Organisation	Role	Detail
Client	Progressive Energy Ltd	Lead Project partner	Hynet coordinator/ Integrator
Consultant	SNC-Lavalin	Technical Advisory/ Design	Undertaking CO_2 transport study and H_2 Production
CO_2 emitter source	Essar Oil UK	Project Partner	Owner and operator of Stanlow Refinery
	CF Fertilisers Ltd	Project Partner	Owner and operator of Ince Fertiliser Plant
	Peel	Project Partner	Land Owner of Protos site
Other	Encirc Glass	Local Industry, Ince	Glass producer
	Cadent	Project Partner	
	University of Chester	Project Partner	
	ENI	Project Collaborator	Owner and operator of Liverpool Bay fields and associated infrastructure

2. Methodology

The project methodology and deliverables are summarised in the flow chart shown below:



The feasibility study objectives were to investigate viable and practical solutions to a CO_2 (rail or road) transport solution. To identify the preferred option, the initial phase of work identified the preliminary basis of design (BoD). This set out the design requirements of the preferred (road or rail) solution; and built on the design requirements listed in the overall project BoD [1]. This enabled a more detailed technical discussion at the formal kick off meeting in August 2019, with the client, Progressive Energy Ltd (PEL). The kick off meeting also confirmed the main client drivers for the project, as follows:

1) To demonstrate technical feasibility (of baseline case, 1.2MtCO_2/yr by road/rail)
2) To determine project costs
3) To undertake qualitative comparative risk (HSSE) assessment.

The project then moved to the data acquisition stage, where through vendor and stakeholder discussion the reviewed options where refined and down selected. This considered available site locations, and transport routings of the road and rail option. At this stage high level technical assessment of the process and transport requirements were also considered, including ISO tank options, and loading/unloading arrangements.

The outcome of the optioneering phase of the project was a collaborative workshop to down-select to one option, for this option to be taken forward to the final cost estimate phase. For this workshop, selection criteria were agreed in advance as follows:

Table 2-1 - Option selection criteria

Option:	Criteria Description:
1. Technical feasibility;	
a. Relates to number of road/rail movements practicalities/operations	Low refers to relatively fewer movements, against baseline case on 1.2 $MtCO_2$/yr, 164 x ISO containers per day
b. Land availability (incl. Utility requirements).	Low refers to ample space, limited constraints and/or utility connections available
c. Any technology limitations	High risk refers to any aspect of chain that is not common/standardised or based on proven technology.
2. System cost	
a. CapEx	Against a simple RAG criterion relative to all options.
b. OpEx	Against RAG criteria, based on design life (which may be short period of 1-3yrs).
3. HSSE perceived comparative risk	Against qualitative assessment (e.g. stored CO_2)
4. Expansion of network.	Ability to expand at later date. Low/Green being strongest case for diversity of source point CO_2 producers located away from pipeline.
5. Flexibility	
a. To scale option up	RAG basis, based on timeline in HyNet project that is has potential to achieve.
b. To scale down	RAG basis, based on meeting a lower than baseline case, e.g. Green if can meet 0.4 MtCO2/yr with limited abortive costs
6. Carbon accountancy (full chain accountability).	
a. Fuel CO_2, NOx accountability	To consider CO_2 associated with transport movements (200g CO_2/km for petrol and 120g CO_2/km for diesel)
b. Alternative fuel possibilities of Road/Rail	e.g. Biomethane, Hydrogen,
7. Reliability	RAG basis, Green being best offered reliability as %.
8. DevEx	RAG basis, development practicalities to implementing. Green for low development requirements.

The results of the option selection comparison is given in Appendix B, as detailed in the optioneering study report [2]. Following the workshop, the option selected to be the focus of this final study report was:

Essar Oil UK, Stanlow Refinery, Rail.

3. General design criteria

This section summaries the basis of design for the selected Stanlow Rail option. This considers a CO_2 rail transport option, using ISO containers to transport CO_2 from Stanlow to Point of Ayr, to meet the baseline case (1.2 $MtCO_2$/yr).

For full basis of design please see the SNC-Lavalin Basis of Design [4]. This details the rail CO_2 transport option and ISO storage tank option. Cryogenic ISO tanks have been selected as a predesigned product for a number of reasons, including:

- Ease of loading/handling; fits on standard 20' containers.
- Existing design standards for Road (ADR) and Rail (RID) & routinely used in transport
- Flexible leasing options, to reduce upfront CapEx.
- Reduces Engineering required to mobilise as a demonstrator project, and so drives down cost.
- Ability to store approx. 20tons liquid CO_2, at ~20bar, -20C. With 31-55 day holding time through insulated double walled pressure vessel [4].

Wider HyNet project detail and context is given in Progressive Energy's basis of design [1]. To clarify the selected option a summary is given below, with further detail provided in section 4.0 & 5.0.

Table 3-1 - Summary of Stanlow Rail Option

Option	Selection
No. of rail locomotives sets	2x (Base Option selected, See section Appendix D))
Length of train	403m
Main route	110miles round trip
Journey time	12hours (2hrs load/4hrs travel/2hrs unload/ 4hrs travel)
ISO tanks per train	50x (on 25x rail wagons)
CO_2 impact of rail journeys (annual estimate)	10.1 tons CO_2 emitted (diesel locomotive) [2]
Liquid CO_2 Sequestered per day	3920t (designed for 1.2$MtCO_2$/yr base case)
Buffer storage at Stanlow Refinery and Point of Ayr.	6x bullet pressure vessels (5.6m x 50m length). 20barg, 25 ^{o}C
Liquefaction cooling Duty*	~29.5MW
Liquefaction Compression Duty*	~15-18MW
Gasification (electrical) Heating duty*	~12MW

* Further discussion in process sizing note [5].

3.1. Site & Climatic Data

The CO_2 emitter locations are shown as Stanlow and Ince in Figure 3-1 below. The point of CO_2 disposal to existing pipeline will be selected as part of this study. This will be at a site at the gas treatment plant at Point of Ayr. The gas reservoir locations for storing the CO_2 in the Liverpool bay are also shown indicatively.

Detail on the exact battery limit (BL) locations is found in the full chain BOD [1] and section 1.4.1.

Figure 3-1 - Map of Hynet Phase 1

Full climatic date is given in Appendix A, from SNC-Lavalin Basis of Design document, [4].

3.2. CO_2 Composition

The table below details the inlet gas stream flowrate and composition, these are taken from the Progressive Energy Basis of Design [Ref. [6]]:

Table 3-2 – CO_2 composition Summary

Flowrates	**Value**
Base case Flowrate	1.2 $MtCO_2$/yr
Low Flowrate	0.4 $MtCO_2$/yr
Conditions	

Pressure	35 barg
Temperature	30°C
Stream Composition	
CO_2	>95%$_{mol}$
Non-Condensables (N_2, Ar, CH_4, etc.)	<4%$_{mol}$
C_2+	<2.5%$_{mol}$
H_2	<0.75 %$_{mol}$[1]
CO	<0.2%$_{mol}$
H_2O	<50ppmv[2]
H_2S	<200ppmv
Ash	<1mg/Nm^3, <1µm

Further discussion on CO_2 inlet composition is provided in the Process Design Technical Note, P02 [7] & Process sizing note [5].

3.3. CO_2 Production rate

CO_2 production rate below, from SNC-Lavalin BOD, A.2.0 Mass Flow Rates, Annual Breakdown [4]:

Inlet operating pressure: 35 barg (to receiving vessel at source)

Inlet operating temperature to receiving vessel at source: 30°C

Required flow rate for:

2023 – 2025	0.4 MtCO_2/yr	100% Ince Fertiliser Plant
2025 – 2027	1.2 to 2.2 MtCO_2/yr	**Design Baseline case**; includes Stanlow FCC, Ince Fertiliser Plant then includes Protos and scaling up of Stanlow FCC by 2027
2027 onwards	3 MtCO_2/yr	Hydrogen production capture introduced, and some other existing sources (e.g. Cement works)

[1] Potential for H_2 content of the CO_2 stream to be reduced to 0.3%$_{mol}$ [Hold 8].

[2] Originally the H_2O specification was for 250ppmv, however it has been verbally confirmed this is being updated to 50ppmv. This document is based on the assumed 50ppmv value which will be officially confirmed during the next phase [Hold 9].

3.4. Existing infrastructure at Stanlow

From the Optioneering Study the Stanlow Rail site was identified as the most suitable location for the surface plant facility for CO_2 capture and loading onto the rail wagons [2].

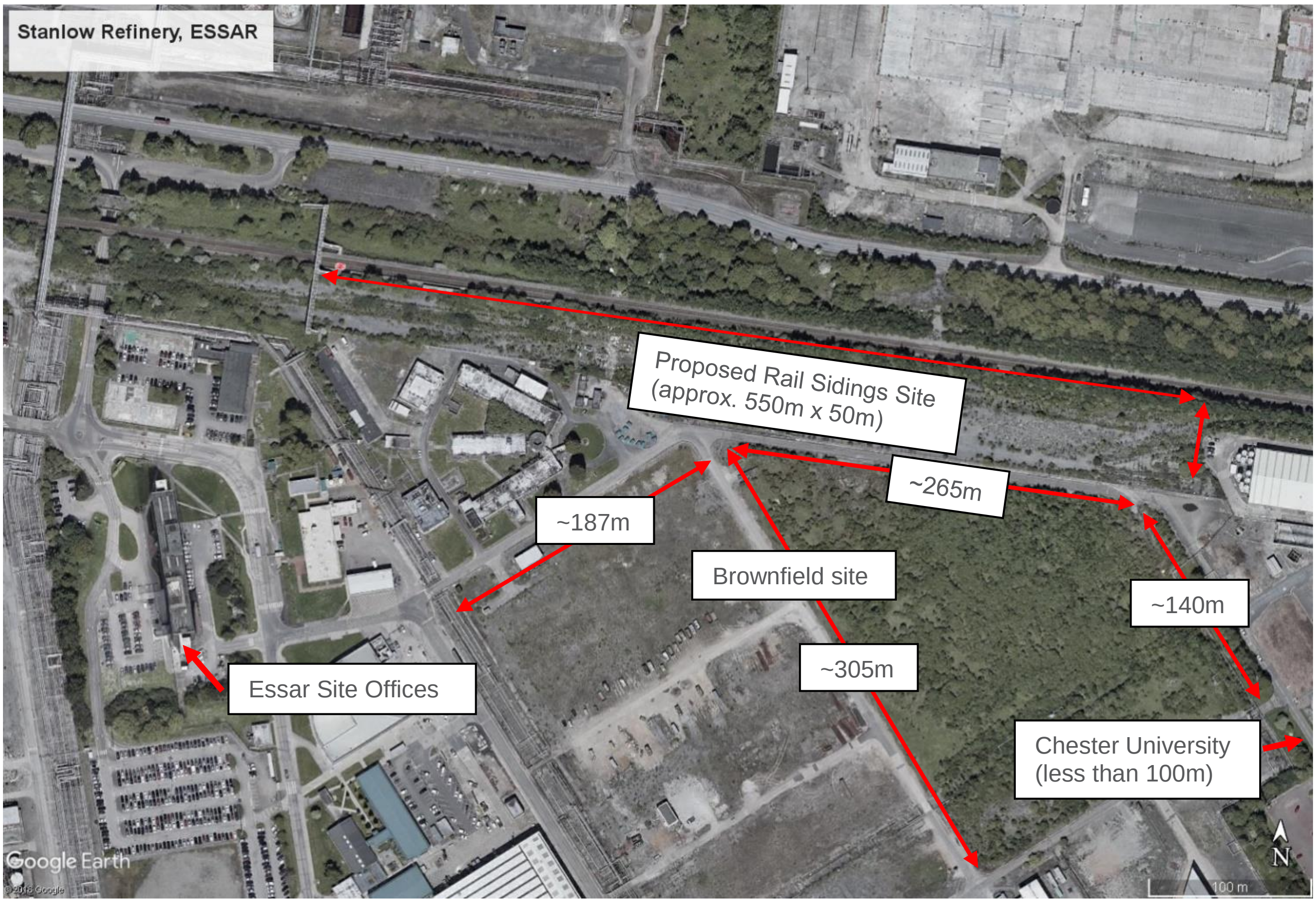


Figure 3-2 – Overview of Stanlow Site

Considering the existing structures at this site, proposed location for connection to mainline at Stanlow is shown in Figure 3-3.

Figure 3-3 – Proposed location for Switches & Crossings (S&C) for connection to mainline at Stanlow

3.4.1. Utilities

The Stanlow site was reviewed against Power and Water requirements for the project. It was identified through stakeholder discussions that there was a potential restriction on cooling water supply. As the volume of cooling water required is relatively high it was assumed that there may be insufficient spare capacity in the host's (Essar) cooling water system to provide this. For this reason, air cooling was selected in the final design. No power availability restrictions were noted, and electrically powered Refrigeration Compressor for the liquefaction unit was selected (see Section 5.1).

3.4.2. Battery limits/ CO_2 connection

The system battery limits will be at CO_2 emitter locations (Stanlow Refinery, Essar and Ince Fertiliser Plant, CF Fertilisers Ltd) and Point of Ayr for discharge.

The identified tie in points have been assessed conceptually from Aerial (google map) plans, but are indicated as follows:

- Refinery Capture: Outlet from capture plant compressor. Essar Oil UK is the Design Authority for the refinery capture plant.
- Fertiliser Plant Capture: Outlet from capture plant compressor. CF Fertilisers is the Design Authority for the fertiliser capture plant.
- Hydrogen Production Plant Capture: Outlet from capture plant compressor. The future operating entity of the hydrogen production plant is currently unknown, but as PEL is the Lead Partner in a project undertaking a pre-FEED / FEED study of the plant they will be designated Design Authority.
- Protos Plant Capture: Outlet from capture plant compressor.

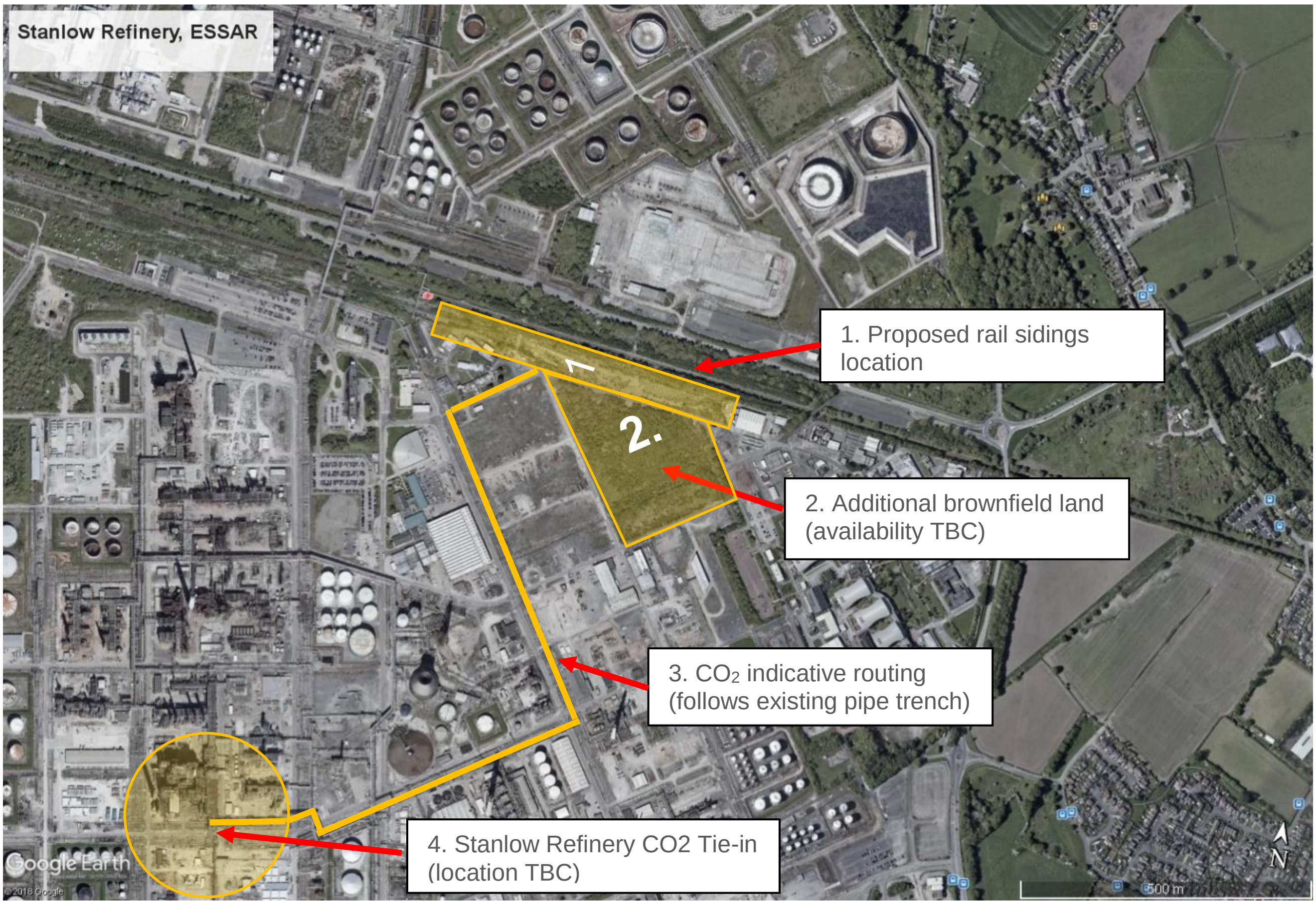


Figure 3-4 – Indicative CO2 tie in location from Stanlow Refinery

Figure 3-5 – Indicative CO2 routing from outlying CO2 producers to Stanlow Site

3.5. Existing Infrastructure at POA

From the optioneering study [2], and driven by the fact a rail CO_2 transport option was selected, the CO_2 regasification and associated surface plant was agreed to be located near the existing gas treatment plant at Point of Ayr (POA). This is located near historic rail sidings, which is assumed could be reutilised (reconnection costs have been factored).

The originally identified (approx. 265m x 75m) surface plant site, within the gas treatment plant compound, was later ruled out. This was driven by the siting of the 6x CO_2 storage bullets, which are considered major accident hazard potential (see discussion in Section 6.0). It was considered a risk that failure of the storage bullets would lead to major damage to the gas infrastructure within the current site and was considered a risk to occupied buildings on the site and the local discovery centre). Therefore, the CO_2 regasification plant location to the South of gas treatment plant is a safety driven decision.

Figure 3-6 –Satellite imagery at POA existing gas treatment plant (Google Earth).

3.5.1. Utilities

A heat source is required for the regasification required at POA from the transported liquid CO_2 to gas in the pipeline. Both electrical and gas heating sources were considered as discussed in the Process technical note [7].

In regard to a suitable gas connection initial enquires were made through the 'SafeDigs' enquiry portal. This looked at available transmission and distribution gas pipeline in the local area from National Grid and Wales and West Utilities. It was noted that the high pressure pipeline is available to the Stanlow and Connah's Quay regions, but did not extend to POA. Detail on the Distribution network around POA was unavailable without more detailed formal enquiries.

For electrical connection, initial enquiries to SP energy networks (SPEN) identified there was no data freely available regarding 33kV transformer loadings. As the heating load would need to be connected to a nearby substation, the local available substations were investigated, which include:

- Point of Ayr Local
- Hamilton Oil
- Nant Hall
- Holywell GSP

It was noted, by visual inspection only, that there is a spare bay in the Point of Ayr local compound that could be used. However, a connection exists to the POA local substation to the POA Gas Processing Plant. It is assumed, for the purposes of this study, that this supply would be sufficient to provide approximately 12MW electrical heating required for regasification. For the next stage of FEED engineering it would be recommended to engage with the local connections team in the SPEN Manweb area. It is likely that grid reinforcement would be required, as well as an assessment against single point failure.

For these reasons a substation cost and associated footprint was included in the final design (also shown in Plot plans, given in Appendix C).

3.5.2. Battery limits/ CO_2 connection

The point of CO_2 discharge is identified at POA, with tie in to the gas pipeline within the gas treatment plant (at a location to be confirmed). Full plot plan layouts are given in Appendix C.

4. CO_2 Rail Transport

4.1. Design Basis

As per optioneering workshop in 18th of September [2] the rail option at Stanlow Refinery was the basis for the cost estimate work (Section 8.0) and further option refinement in this final report. A summary of the selected option is provided below:

Table 4-1 –Summary design basis (Base Option selected)

Option	Selection
No. of rail locomotives sets	2x
Length of train	403m
Main route	110miles round trip
Journey time	12hours (2hrs load/4hrs travel/2hrs unload/ 4hrs travel)
Journeys per rail locomotive per day	2 (4 complete journeys total)
ISO tanks per train	50x (on 25x rail wagons)
Daily liquid CO_2 transported	3920t

It should be noted that the 'base option' selected was the original design basis, see preliminary BoD [4], but this was further investigated to understand if varying the number of trains or ISO tanks per load would optimise the overall total journey costs and process requirements. A summary and the Pros/Cons (See Table 0-6) of a 3x and 4x train option is given in Appendix D, as well as a review of the operational loading/unloading requirements for each (Appendix E). It was found that although a 3x train option allows reduced total staff operators, the increased round trip journey time/fuel outweighs the potential benefit.

4.2. Operational philosophy

Please refer to CCUS project, HyNet Phase 1: Industrial CCUS Pre-FEED Full Chain Basis of Design, [6] for the full chain operating philosophy to be employed on the project.

The following operating hours were used for the design basis:

Table 4-2 – Operating hours

	Rail
Weekdays (Mon to Fri)	Minimal restriction, (may be overnight noise limitations imposed)
Saturdays	
Sundays	Assumed restricted, unavailable

The rail CO_2 transportation was designed with sufficient 'buffer storage' designed to account for the variability of these transportation movements: the buffer storage was sized for 24 hours capacity in the minimum case. This was increased to 36 hours to accommodate some buffer capacity.

[Please refer to Section 5.2 for further discussion on the buffer sizing, as this was recognised to have significant safety (storage of major accident hazard) and cost implications on the overall study].

4.3. Proposed Rail/Civils Design

The proposed rail sidings, shunting and loading facility at Stanlow is given in Figure 4-1. The layout, which is similar in design, is also shown for POA in Figure 4-2. The freight train comes with one locomotive. This means that at each end appropriate siding is required to accommodate locomotive shunting.

[For full plant surface layout, at Stanlow and POA, please see Appendix C]

4.3.1. Rail Sidings location

Figure 4-1 – Stanlow Refinery Proposed Rail sidings

Figure 4-2 – Proposed unloading sidings at POA

4.4. Rail transport Routing

Indicative routing from Stanlow to Point of Ayr is shown in Figure 4-3 below. The full routing and details of route availability is given in the supporting Rail Technical Note [8]. There are alternative rail routes that provide alternative diversionary routes if the main route is unavailable due to a Network Rail engineering blockade. These usually happen during bank holidays, weekends or during the late evenings mid-week, circa 22.00 – 0500. The alternative routes are longer in distance and therefore would require a revised train plan.

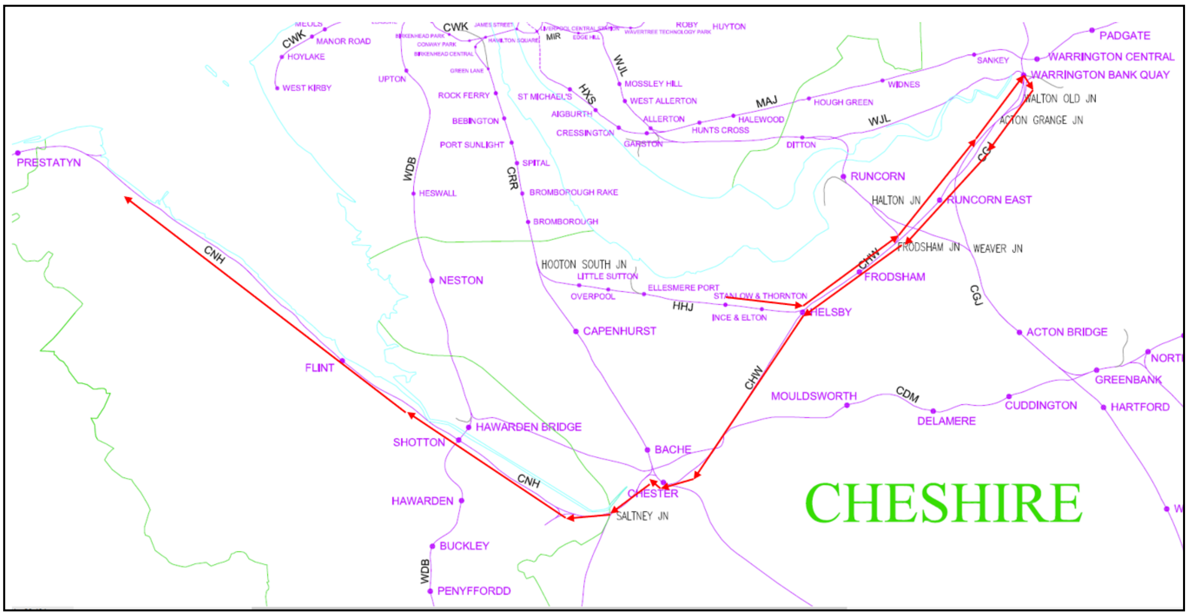


Figure 4-3 – Stanlow to Point of Ayr Rail Route

4.4.1. Civils

When developing the cost model, the following infrastructure items were included, more detail is provided in the full CapEx cost estimate report [9].

- Rails ; CEN56E1
- Sleepers; F27 concrete
- Excavation and disposal
- Ballast & Type 1 fill
- Geotextile; TED4 Composite
- Fabricated Track Drainage Pipe
- Solid Track Drainage Pipe
- Pea Gravel to surround Drain Pipes
- GRP Drain Chambers
- GRP Soakaway Chambers
- Signalling and Controls; Suitable for CEN56E1 and speed of 30mph

4.5. ISO tanks on train wagons

The carriage of liquefied CO_2 by rail is governed by Appendix C - Regulations concerning the International Carriage of Dangerous Goods by Rail (RID), of the Convention concerning International Carriage by Rail – (COTIF), latest issue January 2019. An indicative model of ISO tank storage on rail wagons is given in Figure 4-4. In the recommended design each ISO tank would have a built-in transfer pump. These are typical in CO_2 transport and have a capacity of 15,000kg/hr, this assumes a ~1.5 hour loading/emptying time (as discussed further in Appendix D). The full ISO tank specification is given in Section 6.4 of the SNC-Lavalin BoD [4]. Liquid CO_2 is stored at 17-24bar, under double walled cryogenic containers. These store the liquid CO_2 at approx. -20ºC and can do so for up to 55days (pressure dependant). One ISO tank holds 19.6 tons.

Figure 4-4 - Indicative model of wagon 40' with two ISO tanks

It is assumed the ISO tanks would be procured under a leasing model, in a similar manner to the rail wagons/locomotives. This approach is preferred to outright purchase, as the project initial CapEx is reduced, and the approach transfers risk of ownership/maintenance to the lease owner (e.g. ASCO, Eurotainer). Through vendor discussions there were no perceived constraints in this leasing model, however the large number of required ISO tanks (100x ISO tanks for Base Option) would require early engagement to avoid any long lead procurement delays. An indicative OpEx was quoted by one supplier of €75.00/day (with transfer pump) for a period of 1 year minimum. It was noted that multiple units with transfer pumps, may be difficult to obtain, and the pump cost may be €25-30k in addition to an ISO leasing option.

The coupling/uncoupling arrangement from individual ISO tanks was reviewed at a high level. To minimise additional risk of lifting operations/mechanical handling, the ISO tanks would be filled/emptied in situ. An indicative process design concept included a main distribution header with a series of control valves and quick coupling unions to each ISO tank (see Section 5.3). The coupling arrangement is common in the food grade CO_2 industry, albeit on a smaller operational scale. The start sequence would be controlled by a master valve, and operator controlled. Each transfer pump would then be turned on in sequence to fill the individual ISO tanks. A period of 5mins was assumed for connection and initiation, and 5mins for decoupling and safe shut down. The operational implications of this are discussed in more detail in Appendix D.

There is opportunity to refine the process 'loading/unloading' design by engineering a bespoke design to the purpose. However, moving away from standardised equipment may add cost and impact the achievable project implementation dates. For this level of concept engineering, it was assumed that the engineering required would outweigh any cost benefit.

5. Proposed Process Design

The process design of the system originates from the Progressive Energy BoD [1] and SNC-Lavalin BoD [4] which specify the flowrates and composition of the CO_2. During initial developments some changes were made such that the Base Case flowrate was set at 1.2 $MtCO_2$/yr with a Low Case of 0.4 $MtCO_2$/yr. In addition, the H_2 limit was reduced to <0.25mol%, though all other impurity limits remained unchanged.

Based on the specified flowrates and compositions the preliminary process design [4] was produced and is discussed in detail within the Process Design Document [7]. This document firstly confirmed the viability of liquid CO_2 transportation and confirmed the preference for transport as a liquid rather than a gas. Then the document laid out a preliminary process design for both the liquefaction and regassification plants. Following this, indicative CapEx, OpEx and plot space requirements were estimated based on previous project experience. In addition, the Process design document raised the possibility of a simplified liquefaction plant design.

Following on from this preliminary report the process design was developed in more detail within the Process Modelling and Sizing Technical Note [5]. The modelling of both plants was conducted using the HYSYS modelling software with focus on the selection of the preferred liquefaction plant configuration and optimisation of its design to minimise utility consumptions. The model was then used as the basis for the sizing of the process equipment for feeding forward to the Sized Equipment List [10] for use in the cost estimation process.

5.1. Liquefaction

Based on the Process Modelling and Sizing Technical note, the liquefaction plant configuration will be as shown in Figure 5-1.

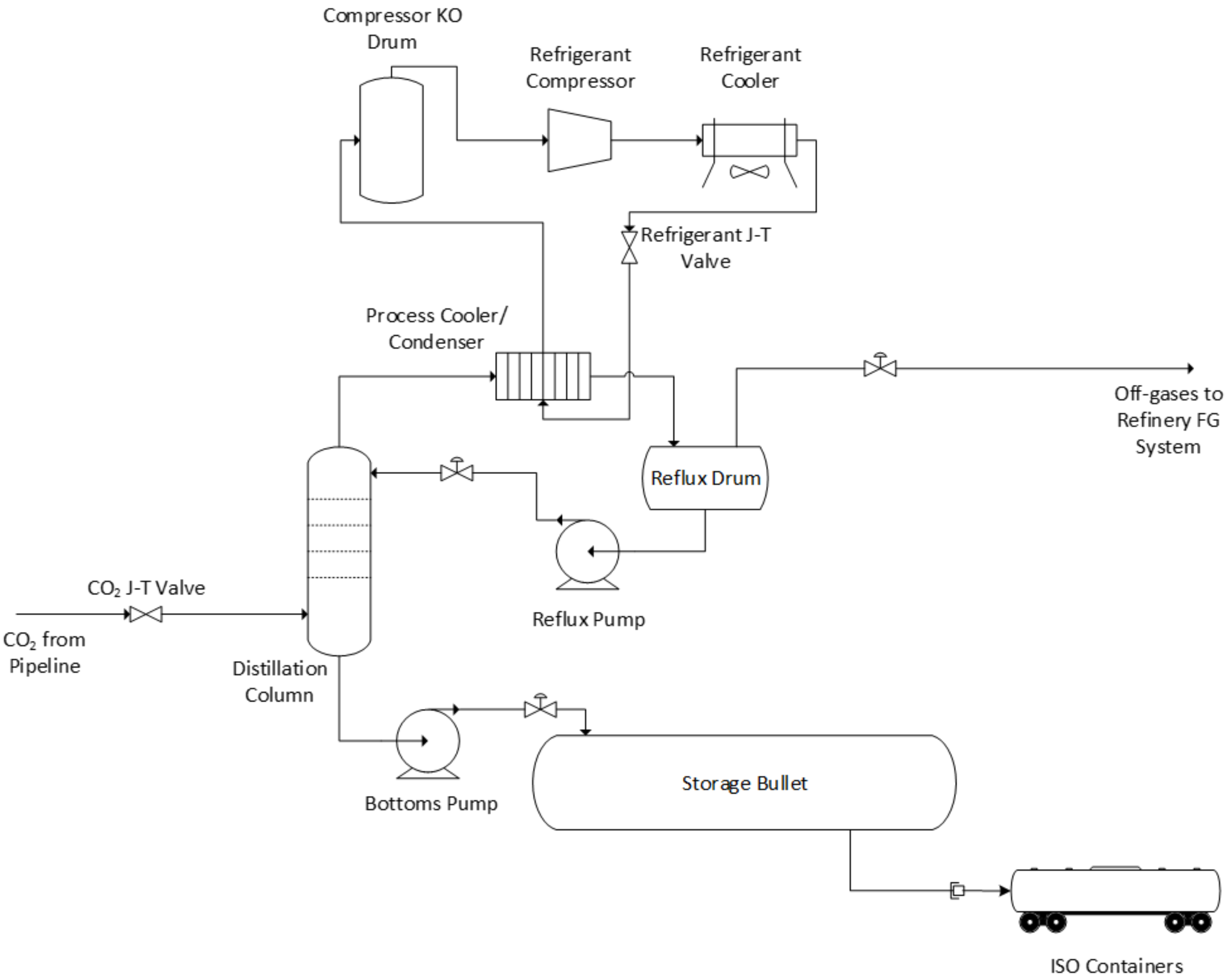


Figure 5-1 - Liquefaction Plant Configuration

In this configuration incoming CO_2 is firstly routed to a J-T Valve to drop the pressure (to ~20 barg) while simultaneously reducing the temperature. CO_2 is then routed to the Distillation Column where it is contacted against falling liquid CO_2 from the Reflux Drum. Any uncondensed CO_2 is routed to the Overhead Cooler/Condenser where it is cooled to -40°C by a Refrigeration System. The mixed liquid/vapour stream from this Cooler is routed to the Reflux Drum to separate liquid CO_2 from the vapour contaminants (H_2, Argon, CH_4 etc). The vapour contaminants are routed to the Stanlow Refinery Fuel Gas (FG) system where any combustible components are utilised. Meanwhile liquid CO_2 from the Reflux Drum is pumped back to the Distillation Column where it is contacted against the incoming gaseous CO_2. Liquid CO_2 from the distillation column is pumped out of the column to the buffer storage (see Section 5.2).

The Refrigeration System will feature a mixed ethane/propane refrigerant circulated by the electrically powered Refrigeration Compressor. This is expected to be a multi stage centrifugal type compressor, but the type will be confirmed during FEED engineering. The warm gaseous outlet from the compressor is routed to an air cooler exchanger to remove the heat and condense the refrigerant stream. The refrigerant stream is then routed to a J-T valve where it is flashed to reduce the temperature before being routed to the Process Cooler/Condenser to provide the cooling duty to the liquefaction system. Gaseous refrigerant is then passed through the Compressor KO Drum to remove any liquid droplets before being routed to the Refrigerant Compressor Inlet.

5.2. Buffer store

Buffer storage of CO_2 is required to balance out the continuous operation of the process plants and batch operation of the CO_2 movements. As described in Section 4.2 a total of 36 hours of CO_2 storage will be provided at both the liquefaction and regassification plants to mitigate against the need for CO_2 venting due to trains operating only 6 days per week. This storage volume will be provided in the form of six horizontally mounted bullets where CO_2 is stored at conditions of ~20 barg and ~-25ºC. The buffer storage at both the liquefaction and regassification plants are identical.

During costing it was noted that the bullets constituted a large proportion of the overall system CAPEX (see Section 8.0) and thus preliminary investigations were conducted to assess potential options for cost savings. The reviewed options include:

- Conducting 7 day per week rail transport operations, possibly with a reduced service on a Sunday. However, this may not be possible due to the closure of lines.
- Providing fewer bullets with larger diameters which reduces the total amount of steel required to provide the necessary storage volume. However, the increased volume of CO_2 volume in a single bullet increases the risk in the event of a loss of containment. In addition, the larger diameter could present a problem during the delivery to site with clearances etc.
- Reducing the storage volume requirements from 36 hours to 30 hours (or lower). However, this comes with an increased risk of venting if there is any delay in train timings and thus would reduce the overall CO_2 capture rate.
- Reducing the storage volume at the regassification facility only and running that facility at a reduced capacity during Sunday operation. However, this would require the plant to make up for the loss of capacity on Sundays during the rest of the week. This would increase the size of all other equipment on site and result in an increased CAPEX.
- Consider increased CO_2 venting arrangements to reduce the requirement for buffer storage. This may have environmental permitting restrictions, and potential reputational impact on the project.

These should be investigated during any future phases to identify the optimum solution for the project, against the project core drivers.

5.3. CO_2 Filling

As discussed in Section 4, CO_2 is transported by train in ISO Containers with 50x ISO Containers per train. During loading, the train will pull into the rail siding where operators will connect each ISO Container individually to a local connection point. Each connection point will in turn be connected to a main distribution header running along a pipe rack alongside the siding. Once connected, CO_2 will be pumped directly from the storage bullets to the ISO Containers using the individual pumps supplied as part of the ISO Container.

5.4. CO_2 Emptying

Like the filling of CO_2, emptying will be accomplished by the train pulling into the rail siding (at the regassification plant) and each ISO Container will be connected individually, via a connection point, to a collection header on a pipe rack running alongside the siding. Again, the transfer will be accomplished using the pumps attached to the ISO Containers and CO_2 will be pumped directly from the containers to the Storage Bullets.

5.5. Gasification

The regasification of the CO_2 is a much simpler process than liquefaction. Liquid CO_2 from the storage bullet is pumped, by the CO_2 Gasification Pumps, to the required outlet pressure before being gasified in the Electrical CO_2 Gasifier. Gaseous CO_2 from the gasified is routed to the outlet pipeline for connection to the gas field.

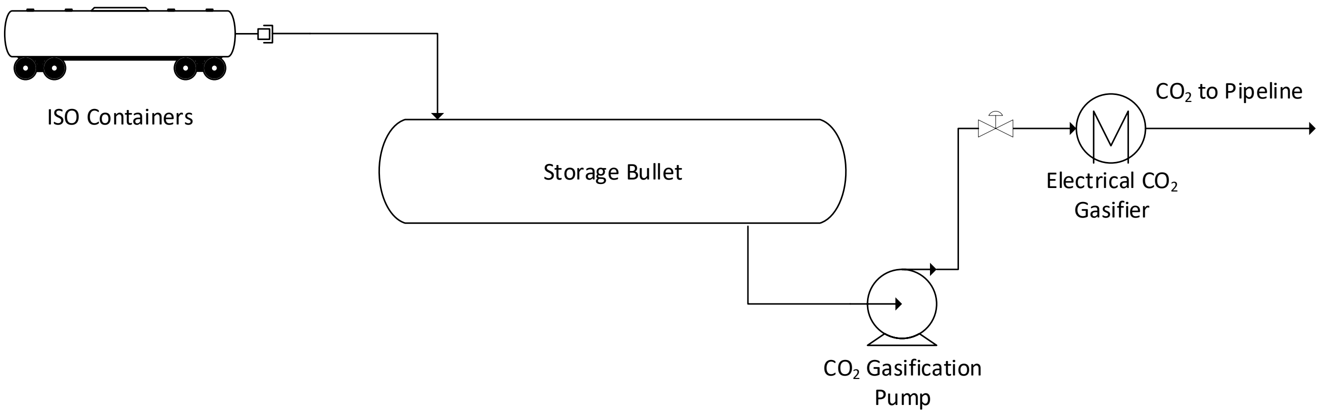


Figure 5-2 - Regasification Plant Configuration

It is noted that, as discussed in Section 3.5.1, the selection of electrical power as the preferred heating medium is subject to further study. As discussed in the Process Modelling and Sizing Technical Note [5] there are several other heating options including seawater, air, combustion heat and cold energy recovery. However due to the relatively low CapEx, plot space requirement and lack of direct CO_2 emissions, electrical power has been selected as the preferred medium. This selection will be assessed as part of the FEED phase of the project.

6. HSSE assessment

As part of this feasibility study, a preliminary review of the CO_2 major hazard safety issues was completed by a SNC-Lavalin Chief Process Safety Engineer. It is emphasised that this high level review is not a detailed safety study or risk assessment, but simply aims to identify whether there are any ‘red-flag’ issues in terms of major hazard safety, and to identify some of the issues which will need to be considered in a more detailed study. The findings from this review, are given in the provided technical note discussion [11].

The summary points from this review are as follows:

- The fact that CO_2 is not currently classified as a dangerous substance means that there is no current requirement for a CO_2 installation to obtain Hazardous Substances Consent or to comply with the COMAH Regulations (unless there are other dangerous substances present). Therefore, it is not expected that HSE would be consulted on any planning application, and potentially advise against the granting of planning permission on safety grounds. Nevertheless, the HSE has made it clear that under the HSWA operators of CO_2 CCUS facilities should undertake reasonably detailed safety studies to help ensure that risks are adequately controlled.
- It is noted that if a project is classified as a Nationally Significant Infrastructure Project then HSE would be likely to provide advice as if the project required Hazardous Substances Consent. The nature of that advice would depend on a detailed assessment of the risks, and the proximity of nearby populations.
- It has been shown that potential major accidents at the Stanlow CCUS facility could have significant effects at distances of up to about 650 m, due to the large inventory in each storage vessel. The likelihood of such events is relatively low (but not negligible), but it would require a detailed Quantified Risk Assessment (QRA) to demonstrate that the risks to those in the vicinity are acceptable.
- One of the greatest causes of concern is likely to be the proximity of the University of Chester, Thornton Science Park. There is a reasonable chance that the risks for this receptor group may be above the levels that are normally considered acceptable, and that the HSE might therefore advise against the CCUS Stanlow location if they were consulted.
- It is noted that the major hazard risks in the Stanlow area are already high, and that there are already some ‘incompatible’ developments in the area, such as the University of Chester, Thornton Science Park. Hence, it may be prudent to consult with the HSE in advance, to ensure that any issues can be addressed before designs are finalised.
- There are also risks associated with the transport of CO_2 by rail. The maximum hazard ranges associated with the failure of a single ISO container are much lower than for the storage vessels, but the probability of failure will be higher (due to the large number of ISO containers and the risk of train accidents) and there is also a potential for the accidents to occur in more populated areas, and hence affect more people. A more detailed Quantitative Risk Assessment (QRA) would be required to assess the levels of risk.

In summary, the preliminary review of major hazard issues has not identified any clear ‘red-flag’ issues. However, for the chosen options, despite that there is no (perceived) necessity to comply with any GB major hazard legislation, it is clear that under the HSWA the HSE expects that operators will manage CCS facilities and control risks in a similar manner to other major hazard sites.

This includes the preparation of a comprehensive site specific risk assessment, as well as compliance with all relevant codes, standards and guidance. It is likely that a reasonably detailed QRA will be required in order to demonstrate that the risks to the public are acceptable. It is recommended that the HSE be consulted for early engagement on some of the issues raised, in respect to the wider HyNet project.

7. CO_2 emissions review

The overarching aim of this project is to sequester CO_2 to safe long-term reservoir storage. Through the full chain process (liquefaction, buffer storage, loading, ISO tank storage, and unloading), there is inherent energy consumption and an environmental impact through unwanted emissions. It is important that these are identified, measured and minimised to achieve the wider HyNet project ambitions. For this reason, these have been considered as part of this feasibility study below, in the following areas:

- Transport fuel
- Liquefaction/ Process Plant
- Regasification heating.
- Other environmental pollutants.

7.1.1. Transport fuel

Table 7-1 - Indicative carbon assessment Rail

	Daily total distance, miles (km)	CO_2 emissions equivalent**, kg (tons)	Total CO_2 transported to CCUS
Rail*	4 x 110miles = 440miles / 704km	10,141kg / 10.1t **(Daily)** 3,103,146kg / 3,102t **(Annual)**	3,920t **(Daily)** 1.2MtCO_2 **(Annual)**

* Assumes diesel train engine, based on 14.7g CO_2/tkm [12]. Calculation excludes mass of train locomotive.

** e.g. 704km * 14.7g/Co2/tkm * (19.6t*50)

It is noted that the emissions from rail transport could be further minimised by adoption of the Hydrogen fuelled train, planned by Alstom in the area [13]. This may facilitate a good demonstrator application and should be considered more closely in the next stage of the project.

7.1.2. Liquefaction/ Process Plant

The major utilities consumed by a CO_2 liquefaction plant are power and cooling water with both being required to operate the refrigeration system. Although small amounts of other utilities will be consumed, these are expected to be of negligible value.

As discussed in the process sizing technical note [5] there is opportunity to simplify the liquefaction unit, given the inlet CO_2 conditions. This would be a simple refrigeration package and flash drum. There is also no requirement for pre-compression. These simplifications in design can result in significant energy savings.

During this process, non-condensable gas (mainly H_2, N_2, Ar and CH_4) will be removed in the vapour phase. Where there is sufficient calorific value in these remaining streams, they will be returned to fuel gas.

Table 7-2 - Summary of Liquefaction Utility Consumption

Criteria	Power/ Energy Consumption	Cooling water
Liquefaction cooling Duty*	~29.5MW	(note air cooling has been recommended [5], CO_2 impact for comparison only)
Liquefaction Compression Duty*	~15-18MW	
Run Energy Consumption (averaged)	0.2MWh/ton (for Base Option/ 1.2MtCO2/yr) (Ref. [7], based on CF Fertiliser Plant estimate)	18 m^3/t
Annual Energy Consumption	24,000 MWh	21.6 Mm^3
CO_2 impact conversion	0.232kgCO_2/KWh (Carbon Intensity forecast UK, available here, accessed 18/12/19)	0.344kgCO_2 equivalent per m^3 (Gov. UK Greenhouse gas reporting)
Annual CO_2 impact (equivalent)	5,568tons	7,430tons

7.1.3. Regasification Heating

The highest OPEX option is likely to be the electric vaporiser due to the high cost of power, therefore this option is selected as the dominant driver in the carbon estimates.

Criteria	Power/ Energy Consumption
Gasification (electrical) Heating duty*	~12MW
Annual Energy Consumption	5,106 MWh (assumes 75% duty)
CO_2 impact conversion	0.232kgCO_2/KWh (Carbon Intensity forecast UK, available here, accessed 18/12/19)
Annual CO_2 impact (equivalent)	1,185tons

The regasification heating was selected as electrical (opposed to gas) to limit fossil fuel use and carbon impact. However, with the current UK energy mix, there is still some CO_2 penalty for electrical consumption, where the carbon intensity would be expected to reduce towards 2030 and beyond.

The annual CO_2 impact of the major process/transport components is relatively minimal against the total CO_2 sequestered (1.2MtCO_2/yr). However, it is not insignificant (approx. 1%) and should be minimised through design optimisation.

7.1.4. Other Environmental considerations

There may be additional (unforeseen) environmental risks as part of the project. This feasibility study has only looked at the major utility and transport CO_2 impacts. The minimisation of arising CO_2 emissions and other environmental impacts should be managed throughout the life of the project via a dedicated environmental manager and risk register (in accordance with ISO 14001:2015).

The following examples are areas for consideration in future phases of the project:

- Minimising fugitive CO_2 emissions from process plant and ISO tanks
- Energy efficiency (i.e. rotating equipment and process efficiency)
- Embodied energy, material selection
- Carbon footprint of materials, e.g. locally sourced where possible, responsibly sourced
- Reputational impact; driving the low carbon economy & implications to wider HyNet project
- Produce designs that acknowledge future risks and opportunities (e.g. climate change impact)
- Reduce waste; circular economy concept & lifecycle considerations
- Monitoring and control; measuring progress made
- Knowledge sharing, using best practise

8. Cost estimate Summary

The following provides a summary of the CapEx, class 4 estimate in accordance with AACEI 18R-97 guidelines, as detailed in the Basis of Estimate document [14]. The full CapEx report and details of included equipment items is given in 5189899-CE-REP-019 [9].

CLIENT: Progressive Energy
PROJECT: CO2 Transport
LOCATION: STANLOW & POINT OF AYR
Project NO.: 5189899

Project Summary

CO2 Transport		Equipment- Incs Packages, ie, Sub-Contact Equip	Materials	Labour	Subcontract- Incs. Buildings & Site Enabling	Licensor Fees, Mgnt, Engineering (Excl Equipment)	Contractor Soft Costs	Total
000A	Site Preparation, Enabling, and Facilities - A1	-	-	609,903.43	16,050,090.26	-	1,605,009.03	18,265,002.72
000B	Site Preparation, Enabling, and Facilities - A2	-	-	608,615.42	16,016,195.25	-	1,601,619.53	18,226,430.20
100	Area 100 Liquefaction - STANLOW	18,102,480.70	659,364.76	6,626,191.50	1,114,050.00	-	4,617,942.83	31,120,029.79
200	Area 200 Transport Containers and Rail Siding - STANLOW & Point of AYR	-	1,616,644.33	1,307,546.00	5,060,550.00	-	575,577.60	8,560,317.93
300	Area 300 - CO2 Storage - STANLOW	20,404,750.18	743,222.62	6,473,370.77	-	-	5,433,887.35	33,055,230.92
400	Area 400 CO2 Loading	235,657.89	198,841.69	190,893.91	-	-	149,948.66	775,342.16
500	Area 500 CO2 Unloading	235,657.89	198,841.69	190,893.91	-	-	149,948.66	775,342.16
600	Area 600 - CO2 Regasificaiton & Storage - Point of Ayr	24,666,798.23	1,675,467.60	10,481,780.10	945,000.00	-	7,805,299.67	45,574,345.60
	Total Base Cost	63,645,344.90	5,092,382.68	26,489,195.04	39,185,885.51	-	21,939,233.33	156,352,041.47
Risk and Contingency P80								
7.3%	Risk P80							11,413,699.03
5.8%	Contingency P80							9,021,512.79
Total								**176,787,253.28**

9. Conclusions

This feasibility study is a counterfactual study to the primary HyNet project. The wider CCUS concept is to install a fixed pipeline from Stanlow (by 2024) and tie into an existing pipeline at Connah's Quay, for CO_2 export offshore.

The study aim was to review a CO_2 transport option, to act as a key enabler for CO_2 capture, transport and storage in the Stanlow/Ince area. The CO_2 transport option, using standardised ISO tanks for storage, was conceptualised as an 'off-the-shelf' project, using established technologies. This was to minimise cost, and design engineering to ensure a safe, 'bankable' design. If implemented the project could offer a fast track solution to demonstrating CO_2 transport and storage in the North West. It also has the potential to capture CO_2 from isolated CO_2 producers in the region (e.g. cement works), thereby extending industrial plant life, as the UK meets an ambitious Net Zero Carbon 2050 challenge.

The study initiated with a definition of the preliminary basis of design [4]. This document agreed a clear scope for the project, including battery limits, design/operational philosophy and functional safety requirements. Following a kick off workshop, the data acquisition was initiated, where discussions were held with key vendors and stakeholders to better understand the operational and technical constraints. At this stage several site options were reviewed and discussed with stakeholders. The options selection workshop refined the options, based on agreed selection criteria, to a single Rail CO_2 transport option at the ESSAR, Stanlow Refinery site.

It should be noted that the outcomes of the optioneering workshop were very closely scored, and in fact the Road option looked to offer particular strength for the Encirc Glass or Stanlow site. Moreover, between the considered rail sites, the main differentiators were around (perceived) stakeholder engagement/willingness and DevEx to implementing.

However, at the Stanlow Refinery site, which offered good land availability and spacing from occupied buildings there was opportunity to reconnect to historic rail sidings. This has the potential to reduce National Rail reconnection costs, which could be a significant barrier to implementing this rail CO_2 transport option. The site also complements well the pre-FEED engineering ongoing in Hydrogen production and fuel switching CHP plant.

The rail option was found to have limited technical or operational constraints. The line capacity had good availability, and despite a slightly longer routing (55miles total) there were no foreseen congestion or resultant reliability issues. The number of trains, and therefore number of ISO tanks requiring filling per siding was investigated. While the loading (coupling) and unloading (decoupling) of ISO tanks was found to be typical in food grade CO_2 transport, it is labour intensive, and there is clear design optimisation possible. For instance, a semi-automated process design could allow multiple ISO tank connections, thereby reducing operator cost (and safety risk). Equally, a common pump could be used to load all ISO tanks at once, rather than individual ISO pumps. However, both of these alternative options would require further (non standardised) design engineering, and therefore move away from the driving objectives of this project, for these reasons they were not explored in detail.

The process plant design is also designed around standardised equipment that is typically used in industry (e.g. food grade CO_2 liquefaction and storage). The base option however (1.2MtCO_2/yr) was challenging to scale common plant sizing to meet. This has potentially elevated overall CapEx to the project (not benefiting from economies of scale, or design optimisation). However, where possible the design was simplified. The design also relies on electrically driven compressors, and electrical heating for regasification. This design choice was determined after reviewing the utility availability at Stanlow and POA. Electrification also complements the low carbon ambition of the project moving forward.

From the CapEx summary (Section 8.0) it was noted that the buffer storage tanks are a large proportion of the overall cost. This offers opportunity for design refinement, by reducing required capacity, or the number of CO_2 pressure vessels (but designed with increased individual capacity). The design refinement should be further investigated, but this may be driven by a safety decision, as the CO_2 buffer stores are a major accident HAZARD potential. For the reason the buffer stores were carefully located away from occupied buildings and orientated with respect to prevailing wind direction (See Appendix C).

As recognised in the HSSE assessment (see Section 6.0) CO_2 is not yet classified as a dangerous substance, yet it is expected that HSE would require detailed safety studies to help ensure risks are adequately controlled. It has been shown that potential major accidents at the Stanlow CCUS facility could have significant effects at distances of up to about 650m, due to the large inventory in each storage vessel. There are equally risks associated with the transport of CO_2 by rail. Despite established regulation for the transport of CO_2 by ISO tank (RID, 2019), a detailed QRA would be required to assess the levels of risk (particularly focussed on areas of dense population, e.g. Chester).

The final CapEx assessment of this feasibility study (as detailed in section 8.0) demonstrates the high cost (circa £176m) of constructing a concept project from many component parts. A £4m network rail connection charge to mainline has been included, which is a middle range estimate from project experience, and the costs can only be fully understood from a more detailed enquiry process. The inclusion of 12x bullet buffer tanks (at £3.8m per tank) is also a substantial proportion (~£45m) of the overall total. Given the cryogenic nature of liquid CO_2, significant insulation costs have also been added.

Based on a ~£176m total cost and 1.2MtCO_2/yr CO_2 sequestered annually, the cost becomes £145 per ton CO_2. There are clear savings that could be made within the project, but it would be a challenge to meet less than £100/tCO_2 without significant simplification in design concept or reliance on existing infrastructure from industry (e.g. the liquefaction plant at CF fertilisers).

References

[1] Progressive Energy Ltd, “Pre-FEED Full chain basis of design, version 1,” May 2019.

[2] SNC-Lavalin, “Optioneering Study report, 5189899-PM-REP-007,” 2019.

[3] SNC-Lavalin, “Kick Off Meeting notes; 5189899-PM-MOM-003,” 2019.

[4] SNC-Lavalin, “5189899-PM-BOD-001 Hynet Rail CO2 study, Basis of Design,” 2019.

[5] Atkins, “5189899-PR-TCN-012 - Process Modelling and Sizing Technical Note (P01),” Atkins/SNC-Lavalin, 2019.

[6] P. E. David Parkin, “Pre-FEED full chain BOD; Hynet Phase 1; Industrial CCUS,” Progressive Energy, 2019.

[7] Atkins, “5189899-PR-TCN-008 - Process Design Document (P02),” Atkins/SNC-Lavalin, 2019.

[8] SNC-Lavalin, “5189899-MD-TCN-009, P02; Rail Transport Technical Note,” 2019.

[9] SNC-Lavalin, “5189899-CE-REP-019, CO2 transport Cost estimate,” 2019.

[10] SNC-Lavalin, “Sized Equipment List,” 2019.

[11] Atkins, “Preliminary Review of Major Hazard Safety Issues; 5189899-PS-TCN-017,” 2019.

[12] Alan McKinnon, “CO2 Emissions from Freight Transport: An Analysis of UK Data",” 2010.

[13] Alstom, “Alstom confirms plans to bring hydrogen trains to the UK,” Alstom, 2019. [Online]. Available: https://www.alstom.com/press-releases-news/2018/5/alstom-confirms-plans-to-bring-hydrogen-trains-to-the-uk. [Accessed 18 12 2019].

[14] SNC-Lavalin, “5189899-CE-PRO-006 Hynet Rail CO2 study BOE,” 2019.

[15] SNC-Lavlin, “5189899-MD-DTS-010_Options workshop_A01,” 2019.

[16] SNC-Lavalin, “Basis of Cost Estimate, 5189899-CE-PRO-006,” 2019.

[17] “Rail Transport & Environment Facts and Figures, Page 9,” CER, September 2015. [Online]. Available: http://www.cer.be/sites/default/files/publication/Facts%20and%20figures%202014.pdf. [Accessed 2019 10 23].

Appendix A ; Site Climate data

Plant elevation

The site is 7m to 15m above mean sea level (Ref. Ordnance Survey 1:25,000 mapping).

Pressure

The site atmospheric pressure is 101.289 kPa.

Temperature

Key temperature data are presented below:

Table 0-1 – Key Temperature Data

Annual mean daily maximum	24.6°C
Annual mean daily minimum	-4.1°C
Annual mean	10.3°C
Maximum recorded	34.5°C[3]
Minimum recorded	-17°C[4]
Maximum Humidity	100%
Minimum Humidity	40%
Design Data	
Winterization temperature	-15°C
Minimum metal temperature	-20°C (Unless specified by process conditions)
Max ambient design temperature	35°C
Air cooler / cooling tower (Discounted top 2% of readings)	22.2°C

Wind

Key wind data is presented below:

Table 0-2 – Wind Historic data

Average wind velocity	18.4 km/h
Maximum recorded wind velocity	168 km/h (Gust)[5]
Design Wind Speed (Vs per BS 6399)	23 m/s

[3] https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/weather/learn-about/uk-past-events/regional-climates/north-west-england--isle-of-man_-climate---met-office.pdf

[4] https://www.bbc.co.uk/news/uk-england-12031709

[5] Bridgewater Weather Station

The prevailing wind is blowing from the South West as can be seen on the wind rose below.

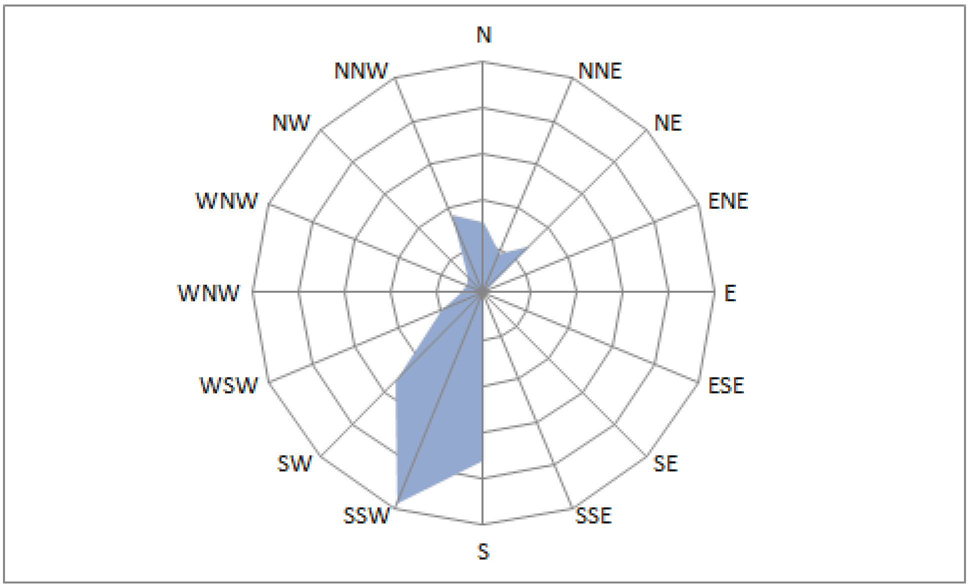


Figure 0-1 - Stanlow Wind Rose

9.1.1. Precipitation

Precipitation data is presented below:

Table 0-3 – Precipitation Data

Average rainfall per annum	815 mm
60 minutes design maximum	20 mm/hr[6]

9.1.2. Snowfall

Average snowfall accumulation is 261 mm per annum[7].

Design snow load is 0.5 kN/m^2 per Snow Zone 3 of BS EN 1991.

9.1.3. Seismic Design Data

There are no requirements in the UK to consider seismic loading and therefore provisions of Eurocode EN 1998 do not apply (reference BS EN 1998-1 Eurocode 8: Design of Structures for Earthquake Resistance).

9.1.4. Ground Conditions

Geological data from the previous operators is unavailable although it is understood the underlying geology of the area is Triassic Sandstone. It is noted that early in Pre-FEED a site visit will be undertaken to improve our understanding of the site with respect to both geology and contamination and it is anticipated that this section of the BOD will be updated accordingly.

[6] http://evidence.environmentagency.gov.uk/FCERM/Libraries/FCERM_Project_Documents/Rainfall_Runoff_Management_for_Developments_-_Revision_E.sflb.ashx

[7] https://www.currentresults.com/Weather/United-Kingdom/snowfall-annual-average.php

Appendix B

	OPTION 1	OPTION 2	OPTION 3	OPTION 4	OPTION 5	OPTION 6	OPTION 7
	Encirc plot	Protos Site	CF fertiliser land	SR refinery	Encirc plot	CF fertilisers	SR refinery
	RAIL	RAIL	RAIL	RAIL	ROAD	ROAD	ROAD
1							
1a	1	3	2	2	1	2	1
1b	1	1	3	1	1	3	1
1c	1	1	1	1	1	1	1
2							
2a	2	3	2	2	1	1	1
2b	2	2	2	2	3	3	3
3	2	2	2	2	2	2	2
4	2	2	2	2	1	1	1
5							
5a	2	2	2	2	3	3	3
5b	2	2	2	2	1	1	1
6							
6a	2	2	2	2	3	3	3
6b	2	2	2	2	2	2	2
7	2	2	2	2	1	1	1
8	2	3	2	2	1	1	1
	23	27	26	24	21	24	21

Figure 0-2 – Options scoring workshop outcome

Appendix C

[Please refer to 5189899-CI-PLP-015 & 5189899-CI-PLP-016_RevP02; to be included as supporting PDFs]

Appendix D

Rail Option 1; 4x train set

- 4no. of train set = at any time there is one train each end (loading/unloading), one time on onward journey and one train on outward journey
- No. of ISO container required per train = 25
- Total number of ISO container = 100
- Train set length = approx. 205m
- Loading/Unloading time = 2hrs
- Minimum siding length required = 285m= 205 for train set +40m S&C+40m shunting
- 1-day loop

Table 0-4 – Rail Option 1; Loading/Unloading

Train1	UL (2hrs)	T+ (4hrs)	L (2hrs)	T- (4hrs)	UL (2hrs)	T+ (4hrs)	L (2hrs)	T- (4hrs)
Train2	T+ (4hrs)	L (2hrs)	T- (4hrs)	UL (2hrs)	T+ (4hrs)	L (2hrs)	T- (4hrs)	UL (4hrs)
Train3	T- (4hrs)	UL (2hrs)	T+ (4hrs)	L (2hrs)	T- (4hrs)	UL (2hrs)	T+ (4hrs)	L (2hrs)
Train4	L (2hrs)	T- (4hrs)	UL (2hrs)	T+ (4hrs)	L (2hrs)	T- (4hrs)	UL (2hrs)	T+ (4hrs)

L Load
UL Unload
T+ Transport to Loading
T- Transport to Unloading
* 2hrs loading/unloading time
** 4hrs journey time

Rail Option 2; 3x train set

- 3no. of train set = at any time there is one train each end (loading/unloading), one time on onward journey or outward journey
- No. of ISO container required per train = 46
- Total number of ISO container = 138
- Train set length = approx. 345m
- Loading/Unloading time = 4hrs
- Minimum siding length required = 425m= 345 for train set +40m S&C+40m shunting
- 2-day loop

Table 0-5 – Rail Option 2; Loading/Unloading

Train1	L (4hrs)	T- (4hrs)	UL (4hrs)	T+ (4hrs)	L (4hrs)	T- (4hrs)
Train2	UL (4hrs)	T+ (4hrs)	L (4hrs)	T- (4hrs)	UL (4hrs)	T+ (4hrs)
Train3	T+ (4hrs)	L (4hrs)	T- (4hrs)	UL (4hrs)	T+ (4hrs)	L (4hrs)

Train1	UL (4hrs)	T+ (4hrs)	L (4hrs)	T- (4hrs)	UL (4hrs)	T+ (4hrs)
Train2	L (4hrs)	T- (4hrs)	UL (4hrs)	T+ (4hrs)	L (4hrs)	T- (4hrs)
Train3	T- (4hrs)	UL (4hrs)	T+ (4hrs)	L (4hrs)	T- (4hrs)	UL (4hrs)

L Load
UL Unload
T+ Transport to Loading
T- Transport to Unloading
* 4hrs loading/unloading time
** 4hrs journey time

As advised by operator company, a minimum of 10% spare ISO containers is recommended for any option. This is for necessary maintenance and replacement of ISO containers.

Base option loading/unloading siding length 400m is suggested in case of both options for future operation flexibility.

Table 0-6 – Summary of Rail options Pros/Cons

Option	Pros	Cons
Base Case	• Reduces no. Journeys & associated CO_2 emitted. Reduced OpEx. • 1 day (24hr) cycle time • Minimises total ISO tanks, x100.	▪ 2hr load/unload time would require 10x staff operators, increased OpEx and Safety risk. ▪ 2hr load/unload time, requires increased process design/engineering ▪ Train near max. length allowable; (~400m). Increased civils CapEx, logistically complex journey.
Option 1	• Increased operators improves redundancy. • Reduced ISOs per train, reduced complexity. • Reduced train length (~205m), reduced civil costs. • Minimises total ISO tanks, x100.	• 2hr load/unload time would require 5x staff operators • 2hr load/unload time, requires increased process design/engineering • Increased journeys, increased CO_2 emitted. Higher OpEx. • Reduced ISO tanks, but same filling requirement/capacity as base case. • Freight operators indicated this may be challenging to accommodate due to capacity constraints (possible reduced availability)

		• Increased OpEx in locomotives/engines.
Option 2	• 4hr load/unload time allows for reduced operators and builds in flexibility. Reduced OpEx, reduced safety risk of personnel. • 4hr load/unload time would require 3x staff operators.	▪ 2 day (48hr) cycle time) ▪ Increased overall ISO tank stock, 138 total. Increased OpEx. ▪ Train near max. length allowable; (~400m). Increased civils CapEx, logistically complex journey.

Appendix E

Review of process loading/unloading operational requirements

The following table represents loading and emptying operations at Stanlow and point of Ayr for three option cases:

- Base Option
- Rail Option 1 (see Appendix D)
- Rail Option 2 (see Appendix D)

Key:

ISO tank ID; Unique identified to each ISO tank

[light green] ; loading/unloading operator staff identifier

[dark green] ; loading/unloading operator staff identifier

Table 0-7 - Base Option, Load/Empty profile

TIME / HOURS

	1												2											
ISO Tank	5	10	15	20	25	30	35	40	45	50	55	60	5	10	15	20	25	30	35	40	45	50	55	60
1	1																			1				
2		1																			1			
3			1																			1		
4				1																			1	
5					1																			1
6	2																			2				
7		2																			2			
8			2																			2		
9				2																			2	
10					2																			2
11	3																			3				
12		3																			3			
13			3																			3		
14				3																			3	
15					3																			3
16	4																			4				
17		4																			4			
18			4																			4		
19				4																			4	
20					4																			4
21	5																			5				
22		5																			5			
23			5																			3		
24				5																			3	
25					5																			3
26	6																			6				
27		6																			6			
28			6																			6		
29				6																			6	
30					6																			6

31	7																			7				
32		7																			7			
33			7																			7		
34				7																			7	
35					7																			7
36	8																			8				
37		8																			8			
38			8																			8		
39				8																			8	
40					8																			8
41	9																			9				
42		9																			9			
43			9																			9		
44				9																			9	
45					9																			9
46	10																			10				
47		10																			10			
48			10																			10		
49				10																			10	
50					10																			10

Table 0-8 - Rail Option 1

	TIME / HOURS																							
	1												2											
ISO Tank	5	10	15	20	25	30	35	40	45	50	55	60	5	10	15	20	25	30	35	40	45	50	55	60
1	1																			1				
2		1																			1			
3			1																			1		
4				1																			1	
5					1																			1
6	2																			2				
7		2																			2			
8			2																			2		
9				2																			2	
10					2																			2
11	3																			3				
12		3																			3			
13			3																			3		
14				3																			3	
15					3																			3
16	4																			4				
17		4																			4			
18			4																			4		
19				4																			4	
20					4																			4
21	5																			5				
22		5																			5			
23			5																			3		
24				5																			3	
25					5																			3

Table 0-9 - Rail Option 2

	TIME/ HOURS																																															
	1												2												3												4											
ISO Tank	5	10	15	20	25	30	35	40	45	50	55	60	5	10	15	20	25	30	35	40	45	50	55	60	5	10	15	20	25	30	35	40	45	50	55	60	5	10	15	20	25	30	35	40	45	50	55	60
1	1																			3																												
2		1																			3																											
3			1																			3																										
4				1																			3																									
5					1																			3																								
6						1																			3																							
7							1																			3																						
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9									1																			3																				
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30	2																			2																												
31		2																			2																											
32			2																			2																										
33				2																			2																									
34					2																			2																								
35						2																			2																							
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40											2																			1																		
41												2																			1																	
42													2																			1																
43														2																			1															
44															2																			1														
45																2																			1													
46																	2																			1												

Rail Leasing, OpEx review

Further to this a high level OpEx Cost comparison is given below. This is only a comparative assessment of the options, based on best estimates, from industry experience.

	Number of Trains			
	Base	Option 1	Option 2	
Number of Trains	2x	4x	3x	
Number of Operators	10	5	3	Stanlow
Number of Operators	10	5	3	Point of Ayr
Total no. operators	20	10	6	
Total Staff Cost	£1,142,000	£571,000	£342,600	
Number of Journeys per day	4	8	4.5	
Days per week		6		
Weeks per year		51		
Number of Journeys per year	1224	2448	1377	
Total Journey Leasing Cost	£18,360,000	£36,720,000	£20,655,000	
Operating Cost	**£19,502,000**	**£37,291,000**	**£20,997,600**	

Assumptions:

- Based on an Operator Staff cost of £57,100 per annum (although it was shown that the relative salary cost has minimal impact on totals).
- Round trip Train leasing cost, £15,000 per journey
- No fuel costs considered, which is expected to add to the cost impact of increased journeys.

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