HyNet CCUS Pre-FEED

Key Knowledge Deliverable

WP3: Fertiliser Capture Report

EXECUTIVE SUMMARY

The CF Industries: Pre-FEED 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 Environmental Limited, 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

The purpose of the Work Package 3 (WP3) Pre-FEED study was to analyse CF's ammonia plant CO_2 capture system at Ince and identify and develop an associated compression scheme for the excess CO_2 in sufficient detail to confirm deliverability of the concept and provide engineering information to enable estimation of CAPEX costs.

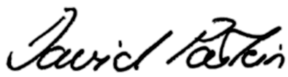
The site currently emits a total of about 700,000 of CO_2 per annum, two thirds of which is captured as part of the production process. It is the largest single separated CO_2 source in the North West and represents a significant opportunity for CF to deliver business benefits by minimising their carbon cost exposure, as well as help underpin the development and delivery of an industrial CO2 capture network for the region going forward.

An optioneering exercise was undertaken to determine the optimal techno/economic solutions for capture and transportation of the excess CO_2 from the site. This included an initial workshop with CF at the site followed by consideration of the potential options and the development of conceptual designs based on the information and data gathered.

Key conclusions and outcomes of the WP3 Pre-FEED study work detailed in this KKD are:

- Agreement by all stakeholders that capture and compression of the excess CO_2 is feasible and that a proposed single blower and compressor concept (with follow on compressor for additional capacity if required), should form the basis of the proposed scheme;
- Confirmation that 330,000 tonnes of surplus CO_2 per annum is typically available from the plant;
- Confirmation that the existing third-party liquefaction plant is fully utilised and unavailable for the excess CO_2 export duty;
- Agreement that the overall compression system design conditions should be based on an inlet of 50mbarg suction pressure at 70°C, and 39barg discharge pressure at 20°C;
- Confirmation that there is sufficient space on the CF site to house the new flash vessel, blower and compressor(s) and that there are adequate utilities and services to meet projected needs;
- Confirmation that no planning or permitting constraints are foreseen;
- Confirmation that a maximum excess CO_2 stream hydrogen level <0.75vol% is achievable in a cost-effective manner by utilising an additional flash vessel in the existing capture train;
- Agreement on the use of proven technology that is readily available from established manufacturers and suppliers to assist in de-risking the project;
- Confirmation that there are no operability issues foreseen with the proposed compression solution;
- Based on the detailed MEL an estimated capital cost of £29.36m million (including risk and contingency);
- Confirmation that the Pre-FEED Report forms a good basis for the next phase of FEED work.

In summary, following a detailed study with all key stakeholders a single option solution was identified and confirmed as the most cost-effective, timely and least risk route for CF to capture and export its excess CO_2 production to an onshore transportation network.



Dave Parkin
HyNet Project Director

GLOSSARY

Abbreviation	Description
AACEI	Association for the Advancement of Cost Engineering International
AN	Ammonium Nitrate
BEIS	Department for Business, Energy & Industrial Strategy
BOD	Basis of Design
CAPEX	Capital Expenditure
CCUS	Carbon Capture Utilisation & Storage
CF	CF Fertilisers UK Ltd
CO_2	Carbon Dioxide
ETS	Emissions Trading System
EU	European Union
FEED	Front End Engineering Design
GRP	Glass Reinforced Plastic
H_2	Hydrogen
HMB	Heat & Mass Balance
IGV	Inlet Guide Vane
kV	Kilovolt
kVA	Kilo Volt Amp
kW	Kilowatt
MDEA	Methyl Diethanolamine
MEL	Major Equipment List
MW	Megawatt
NB	Nominal Bore
NPK	Nitrogen Phosphorous Potassium
OPEX	Operating Expenditure
PEL	Progressive Energy Ltd
PFD	Process Flow Diagram
P&ID	Piping & Instrumentation Diagram
SMR	Steam Methane Reformer
TBC	To Be Confirmed
WP3	Work Package 3

CONTENTS

1.0 INTRODUCTION

This report summarises the Pre-FEED study for the capture and compression of excess CO_2 from the CF Fertilisers UK Limited (CF) plant at Ince, Cheshire. The work was carried out as a Work Package (WP3) within the overall HyNet Phase 1 Industrial CCUS (Carbon Capture, utilisation and Storage) project funded by the Department of Business, Energy and Industrial Strategy (BEIS) and project partners. It was undertaken by a dedicated Progressive Energy Limited (PEL) team in partnership with CF site personnel under the overall project management of PEL.

The core goal of the study was to confirm the feasibility of capturing surplus CO_2, currently discharged to atmosphere, from the existing CF ammonia plant and ensuring that it could be sufficiently processed to meet the CO_2 composition specification for the HyNet CO_2 transport and storage network. The study provides an overview of the existing CO_2 capture process and sets out deliverable and costed plant modifications to ensure pipeline specifications are met for composition, temperature and pressure.

HyNet[1] is an integrated hydrogen and CCUS cluster in the North West of England. PEL is working on a range of activities necessary for the development and delivery of HyNet; some of which have also received funding from BEIS, under its Hydrogen Supply, Industrial Fuel Switching and CCUS Innovation Competitions. With partners, PEL plans to deploy operational hydrogen and CCUS networks in the region by 2025.

2.0 PROJECT BACKGROUND

2.1 Purpose of the CF Project

CF's fertiliser manufacture operation at Ince currently separates outs a total of about 450,000 tonnes of CO_2 per annum, a portion of which is captured as part of the production process and sold to a third-party, leaving a residual emission of approximately 330,000 tonnes p.a. It is the largest single separated CO_2 source in the North West and represents a significant opportunity to underpin and enable the early development of the HyNet CO_2 transportation and storage network.

The integrated manufacturing facility is a major producer of UK agricultural fertiliser. CF currently have limited carbon cost exposure under EU-ETS Phase 3, however this position changes under Phase 4 which comes into effect in 2021. As a business they are

[1] See www.hynet.co.uk

constantly seeking opportunities to minimise exposure to these costs, as well as striving to maintain a competitive position in the wider world marketplace. Reducing EU-ETS allowances, coupled with forecast increases in carbon costs, puts significant commercial pressure on the future viability of the site. CCUS is an attractive option to tackling these potential threats, especially given the significant volumes of CO_2 currently separated at the plant already. Additionally, CF also perceive benefits from the potential marketing value of 'low carbon' fertilisers and feedstock products that a local CCUS network would enable. They are therefore motivated to support this study and explore options and understand costs for CO_2 capture and export from their site.

2.2 Process Overview

The CF plant at Ince manufactures ammonia using the Haber-Bosch (H-B) process. The H-B is a nitrogen fixation process and is currently the most common technology used to produce ammonia. The integrated site operation produces solid fertiliser for direct despatch to customers as both bagged and bulk product.

Key components of the Ince manufacturing facility are:

- Ammonia plant
- Nitric acid plant
- Ammonium Nitrate plant
- NPK plant
- Packaging and despatch plant

The plant uses Natural Gas as the base feedstock, and as part of the production process it removes CO_2 from its process stream using solvent based capture technology.
The site has two main emission points: process CO_2 from the amine plant and flue gas from the Steam Methane Reformer (SMR) stack. CO_2 emitted in the flue gas is outside the work scope of this study.

A proportion of the captured CO_2 from the amine plant is purified and compressed to 20barg for liquified storage in 'bullet' tanks by a third-party. This is exported by road tanker and sold into the industrial gas market (supplying multiple industries). This existing compression plant is unsuitable for use as part of the HyNet project because of lack of spare compression capacity and existing commercial arrangements.

2.3 Site Description & Location

The CF operation at Ince currently occupies a 55-Hectare site in a local area that has been used for chemical manufacturing since the 1920s. The plant was developed in the 1960s by Shell as an integrated part of their oil refinery operation on the nearby Stanlow site, which is now owned and operated by Essar. Existing pipeline easements run from the Ince site to the refinery - this corridor offers a potential route for the CO_2 export pipeline.

The site is located in the North West between the Manchester Ship Canal and the M56 motorway (see Figure 2.1). It is adjacent to the Ince Marshes near the villages of Ince, Elton and Helsby (SJ473765) and lies within the boundaries of Cheshire West and Chester Council.

The site (see Figure 2.2) is best characterised as brownfield land and although no detailed ground condition information for the designated CO_2 compression plant area has been assessed at this stage it is not expected to present any issues. Ground conditions are likely to require piling for foundations, but this is standard practice on site and is well understood.

Figure 2.1: Location of CF Fertiliser Plant

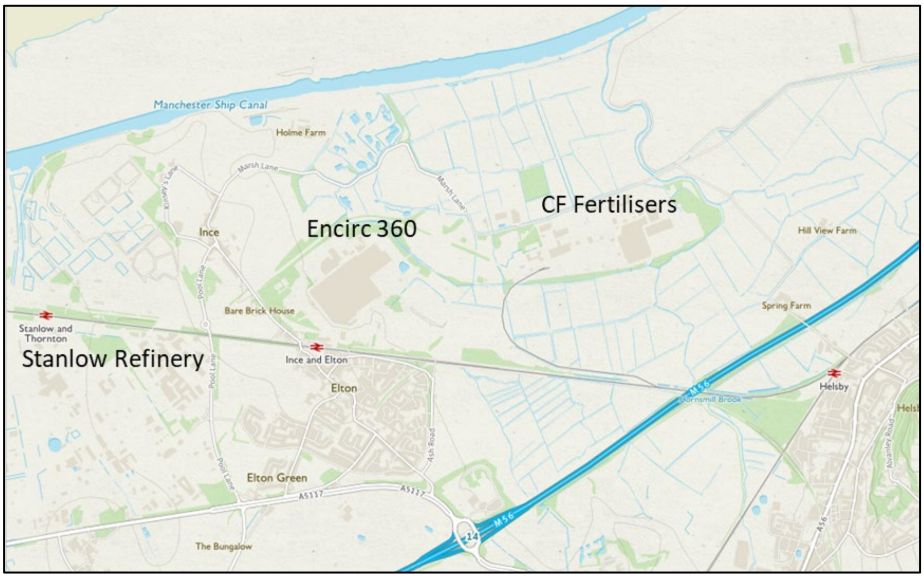


Figure 2.2: View of CF Fertiliser Plant

2.4 Existing CO_2 Capture

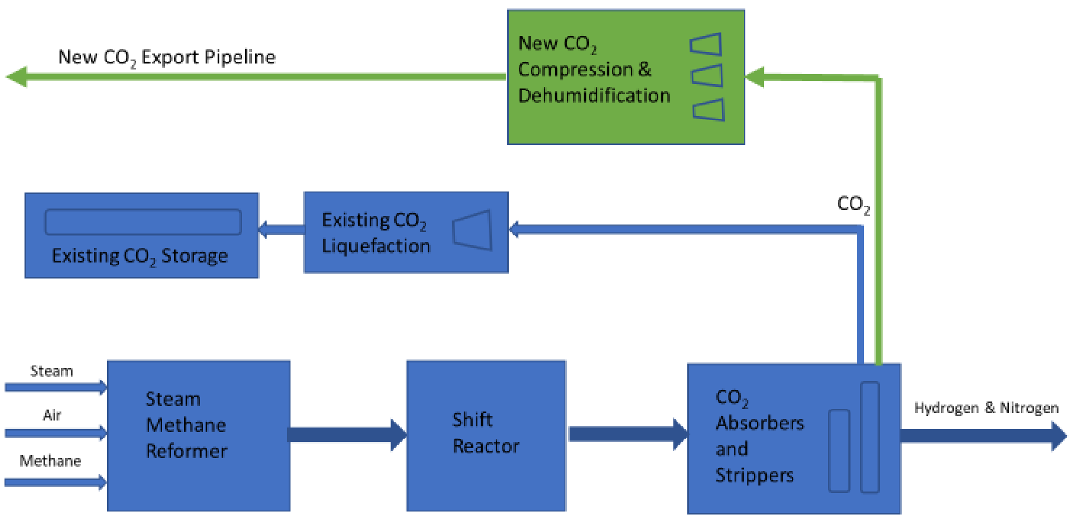
The plant generates Carbon Dioxide (CO_2) as a by-product of the Steam Methane Reformation of the natural gas feedstock which is carried out to produce hydrogen for ammonia manufacture. The CO_2 is removed by a two-stage capture process using an amine solution. Approximately 1.2 tonnes of CO_2 are produced per tonne of ammonia manufactured.

A proportion of this CO_2 is recovered, purified and liquefied on site for sale into the industrial gas market. The remaining CO_2 is currently discharged to atmosphere via a high-level vent attached to one of the two CO_2 absorber columns.

An additional emission of approximately 0.6 tonnes of CO_2 per tonne of ammonia occurs in the flue gas from the steam-raising boiler. Capture of this CO_2 would require the construction of a post-combustion CO_2 absorption and stripping system which is likely to be expensive, and, as mentioned in section 2.2, is outside the scope of this Pre-FEED study.

The high-level schematic shown as Figure 2.3, below, outlines the current and planned CO_2 removal and compression systems.

Figure 2.3: Project Schematic (Existing and Planned CO_2 Systems)



2.5 Existing CO_2 Composition

The typical composition of the recovered CO_2 from the ammonia plant is shown in Table 2.1.

Table 2.1: Typical CO_2 Composition

Component	Typical Content (Dry mole %)	Expected Operating Range (Dry mole %)
Carbon Dioxide	97.8	Balance
Hydrogen	2.0	1.2 - 3.0
Nitrogen	0.2	0.1 – 1.0
Methane	0.01	Trace
Carbon Monoxide	0	Negligible
Argon	0	TBC
Impurities		
Ammonia	400 ppm	-
Methanol	100 ppm	-
Ethanol	<10 ppm	-
MDEA	<50 ppm	-
Piperazine	<10 ppm	-

The CO_2 stream is saturated with water vapour. Water content is 15-20% on a mass basis, depending on operating temperature.

Some of the impurities are water soluble and most of them will be removed along with condensate in cooling prior to and post compression. However, a portion will pass through to the drying section.

2.6 Existing CO_2 Mass Flow & Pressure

Currently, the maximum production rate is 1,150 tonnes/day of ammonia, which generates 1,393 tonnes/day (58 tonnes/hour) of process CO_2.

At typical operating rates on the ammonia plant and CO_2 liquefaction plant, the expected flowrate of CO_2 available for capture would be about 40 tonnes/hour (see Table 2.2).

The vented CO_2 is discharged to atmosphere via a vent stack running at about 1.035 bara, the backpressure being imposed by the vent nozzle. Any new offtake connection will need to be designed to maintain the pressure in the top of CO_2 Flash Column (C1303) at a pressure of 35mbarg.

Table 2.2: CO_2 Flow Rates

	Max production[2]	Typical surplus CO_2	Min surplus CO_2
Total CO_2 (kg/hr)	68,645	-	-
Water Flow (kg/hr)	10,599	-	-
Dry CO_2 Flow (kg/hr)	58,047	39,249	23,349
Dry CO_2 Flow (kg/s)	16.1	10.9	6.5
Dry CO_2 Flow (te/yr)	487,591	329.692	196,134
Temperature (°C)	73	-	-
Vent Pressure (bara)	1.035	-	-

2.7 CO_2 Network Requirements

In line with the baseline CCUS system requirements the new CO_2 compression plant will supply at a fixed pressure of 39barg and temperature of 20°C at the battery limit. The CO_2 will feed the 'collector' network as detailed in the overall HyNet Phase1: Industrial CCUS Pre-FEED Full Chain Basis of Design[3].

The exported CO_2 will also need to meet the baseline CO_2 composition requirements as also detailed in the above Full Chain BoD[4]. All industrial capture sources to the network will need to meet the same CO_2 specification. The transport and storage system baseline 'Low H_2' case specification is detailed in Table 2.3 below.

Table 2.3: Baseline CO_2 System Composition[5]

Species	Limit
Ash	<1mg/Nm³, <1µm
C_2+	<2.5mol %
Carbon dioxide (CO_2)	>95 mol%
Carbon Monoxide (CO)	0.2%

[2] Based on Max CO_2 production rate of 1,150te/day with zero liquefaction offtake
[3] Section 2.6 refers
[4] Section 2.13 refers

[5] Note: Ongoing flow assurance and storage well modelling may result in variations to the above limits in the final CCUS Full Chain Report. These will need to be incorporated into the final WP3 CF Design Basis.

Hydrogen (H_2)	<0.75 mol%
Water (H_2O)	<50 ppmv
Hydrogen Sulphide (H_2S)	<200 ppmv
Non-condensables (N_2, Ar, CH_4, etc.)	<4 mol%
Nitrogen oxides (NOx)	<50 ppmv
Sulphur oxides (SOx)	<50ppmv
Oxygen (O_2)	<10ppmv

3.0 SPECIFIC PROJECT OBJECTIVES

The objectives of the WP3 Pre-FEED Report are to document the existing CF capture plant, develop an agreed and costed engineering concept to meet transport and storage system specifications, and record all findings in such a manner that an engineering contractor could use the study to plan and execute a full FEED study. Specific deliverables include:

- A Process Flow Diagram (PFD)
- A Heat and Mass Balance
- A Preliminary Plot Plan and Equipment Layout
- A cost estimated Parts and Major Equipment List

The above deliverables are included in this Pre-FEED Report, along with the project development and optioneering process description.

4.0 PROJECT DEVELOPMENT PROCESS

The following sections describe the process undertaken by the WP3 study team in developing the options and technical solutions for the capture, compression and transportation from the CF site. This process included an initial workshop with CF stakeholders followed by analysis of the potential conceptual designs and solutions that were considered viable.

4.1 Basis of Design

Following the initial CCUS Full Chain project kick-off meeting a specific WP3 kick-off workshop and site visit involving key project and CF personnel was held at the CF plant to ensure existing knowledge and all operational requirements of the facility were fully understood and accounted for in the development of potential solutions. Prior to the workshop a questionnaire was issued to maximise the effectiveness of the session.

The workshop included understanding and documenting fully the following:

- Existing process plant design and capture arrangements
- Confirmation of existing CO_2 composition and volumes, utilities, interfaces, potential site locations, consenting issues and any other possible constraints and limitations (Note: utilisation of the existing third-party CO_2 compression assets were discounted from consideration based on commercial and compressor capacity constraints)
- CF's views on required duty, conceptual design and system performance.

The first main activity of the Pre-FEED process was confirmation of the Basis of Design (BoD)[6]. This document dealt specifically with Work Package 3 (WP3), covering CF Fertilisers' existing ammonia production and capture plant at Ince. It set out the proposed technical basis for CO_2 capture, compression and dehydration on the site up to the interface with the site CO_2 offtake pipeline.

The BoD document informs the final development of the compression train concept, a preliminary plot plan and a cost estimated Major Equipment List. It formed the basis of this WP3 Pre-FEED report which enables the full FEED study to be undertaken. It is recognised that the BoD will need to be continually updated to reflect and accommodate the local and wider system design development and prior to the commencement of a full FEED.

4.2 Initial CO_2 Compression Concept

Preliminary consideration of the CO_2 compressor design required to meet the overall Full Chain BoD technical and operational requirements indicated the following high-level concept and considerations for the dehydration and compression system:

- Three new 50% duty compressors, each with a capacity of 20 tonnes CO_2/hour. providing 50% redundancy under normal operating conditions. This configuration would also be capable of taking the maximum captured CO_2 when the third-party liquefaction plant was non-operational.
- Consideration to be given to a suitable design margin for potential future expansion and variations in the CO_2 composition and operating conditions.
- Determination of optimal suction pressure will be needed during the conceptual design stage given the extremely low capture plant CO_2 outlet pressure and existing third-party offtake connection.

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[6] CF Industries: Basis of Design (Document No. P1131.WP3.04.001)

- Conceptual design to accommodate the removal of excess hydrogen to meet the CO_2 system requirements of <0.75mol% H_2, especially during start-up phase.
- Consideration to be given to return of excess hydrogen to CF at 25-30barg.
- Wastewater from the drying process to be returned to CF condensate system.
- Consideration to be given to relocating the atmospheric CO_2 emission point to assist tie-in.
- Additional design considerations related to Start-up/Shutdown scenarios and Over/Under Pressure protection. These will need to be subject to detailed study at the FEED study stage.

4.3 Proposed CO_2 Treatment & Compression Concept

The proposed WP3 concept design for hydrogen removal from the excess CO_2 stream and export compression and dehydration plant to be located on the CF site is based on the design parameters, design basis and site information contained within this document. Final design will be subject to a full FEED process and optimisation.

Following extensive discussion and optioneering with CF, dialogue with suppliers and further techno/economic evaluation, the following design solutions for CO_2 removal, excess hydrogen and water removal and compression plant have been developed.

4.3.1 Hydrogen Removal

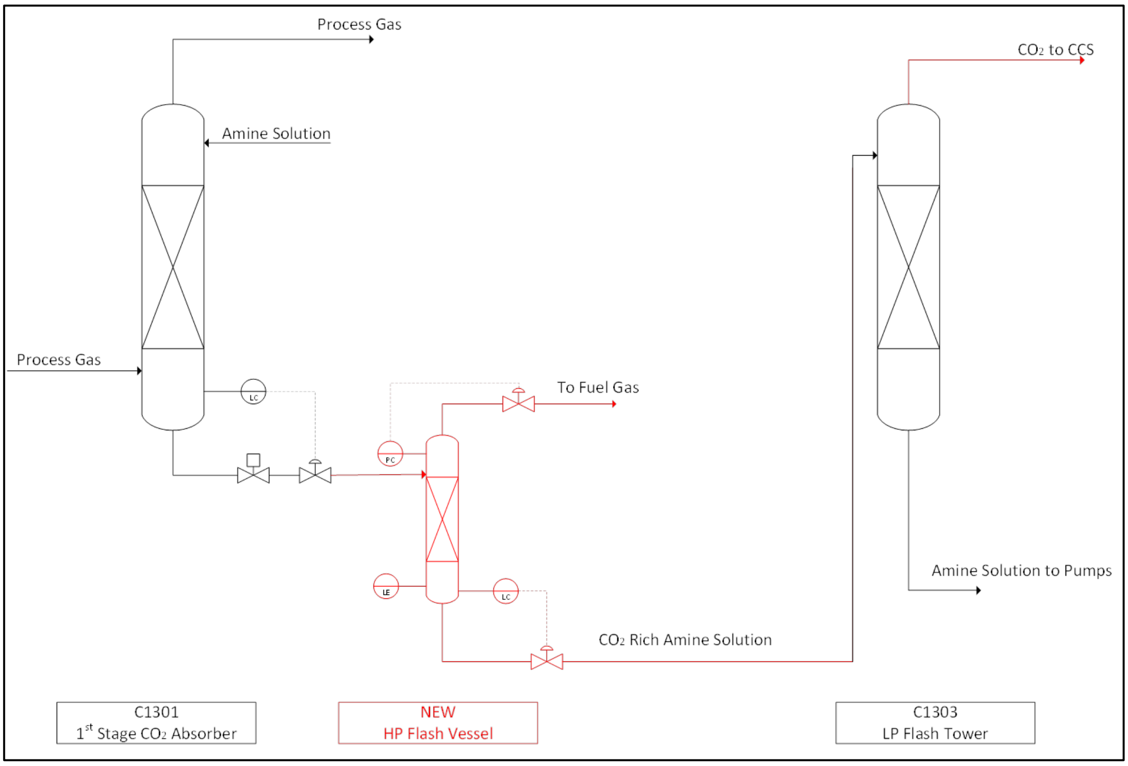
Underlying background to the required treatment of the CO_2 stream are detailed in Appendix A.1.0: Impact of CO_2 Stream. As outlined in the BOD and Section 4.2 above, the level of hydrogen in the exported CO_2 stream needs to be <0.75mol%. Several options to reduce the level from the current ~2vol% were evaluated. The preferred solution is for the addition of a new high-pressure flash vessel in the aMDEA stream from the first stage CO_2 absorber column (C1301) to the low-pressure flash vessel (C1303). This allows precipitation of the hydrogen from the solvent scheme, reducing its level in the final CO_2 stream. It is shown schematically in Figure 4.1.

The design proposal would result in the loss of about 3 tonnes/hour of CO_2 to the fuel gas system, representing 5.6mol% of the total CO_2 captured by the removal system. This CO_2 slip is a function of the desorption characteristics of the amine being used, in that selectivity is not confined to a single gas. It would be theoretically possible to introduce a further separation stage, followed by additional processing of the CO_2, but this would introduce further capital cost, which is not thought to be justified by the reduction in EU-ETS charges.

Key elements and considerations of the proposed design are:

- Estimated HP flash vessel dimensions (as determined by preliminary system modelling): height 23.2m, internal diameter 3.8m
- Normal operating pressure 5.5barg, max operating pressure 9barg
- Associated level and pressure control systems
- Associated protection systems (high and low-level trips)

Figure 4.1: Schematic of Proposed Hydrogen Removal Vessel



4.3.2 Compression Configuration

Following consultation with CF, discussions with suppliers and further techno/economic analysis the preliminary compression design concept set out in the BOD of three 50% duty compressors has been revised to a single 100% duty compressor, with the possible future addition of an additional 50% duty compressor should additional CO_2 become available. The 100% duty is sized such that the typical flow would be accommodated by the compressor turned down to its full extent without utilising recirculation. This would give some capacity variation in both directions by opening the IGVs for increasing flow and recirculation for reducing flow.

The compressor will be fed by a single CO_2 blower sized to accommodate the full CO_2 output of the facility i.e. the combined third-party offtake and the proposed export CO_2. This concept will ensure full CO_2 extraction from the existing venting system and provide controlled input conditions to both the new compressor and the existing third-party liquefaction plant compressors.

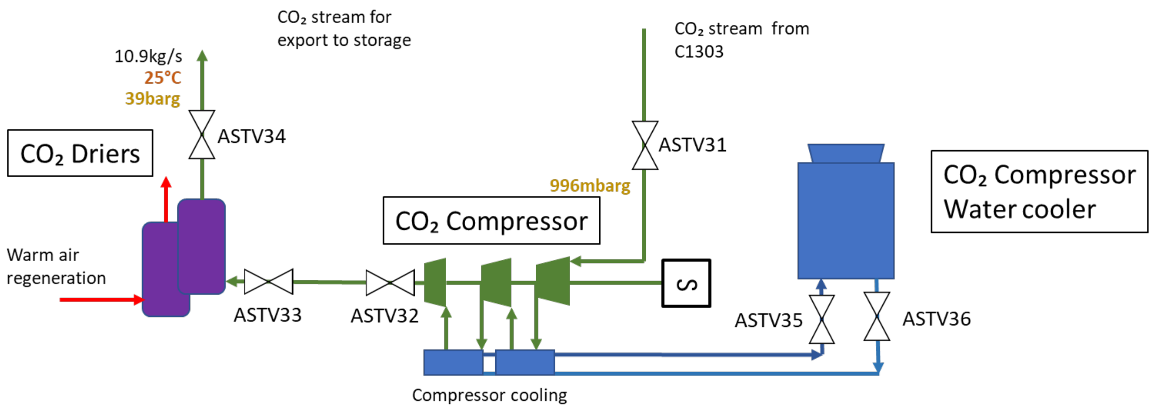
This configuration (as shown in Figure 4.2), provides optimal overall compressor operation and turndown performance while meeting fully the business and operational needs of CF in the most cost-effective manner.

The key elements of the proposed solution are:

- One continuous duty CO_2 blower rated at 19.76 kg/sec (wet) with 1barg discharge pressure and 35mbarg suction pressure at 70°C with 900kW motor drive, with outdoor acoustic enclosure, using a MAN RG 71-1 as a representative supplier model
- One continuous duty centrifugal compressor rated at 15.1kg/sec (wet) with 39barg discharge pressure and 1barg suction pressure at 73°C with 3.3MW motor drive, using a MAN RG 40-4 as a representative supplier model
- Acoustic weatherproof building sized to take the RG 40-4 compressor and associated equipment (approximately 20m x 36m)
- Hybrid cooling tower system matched to CO_2 compressor cooling requirements
- Desiccant CO_2 drying bank for 39barg, 35°C incoming saturated CO_2 stream down to <50ppmv
- Switchgear and C&I enclosures (approximately 20m x 10.5m)
- Connecting CO_2 pipework, knock-out pot(s) and condensate return system

The proposed concept outlined above utilises proven technology that is readily available from established manufacturers and suppliers to the energy and process industries. The equipment specified has a well-established operational track record operating in the field with CO_2, thereby reducing the overall risk profile of the compression plant and associated interfaces.

Figure 4.2: Schematic of Proposed CO_2 Compression System



4.3.3 Associated Process Flow Diagram and Heat & Mass Balance

Based on P&IDs and PFDs provided by CF a process flowsheet was produced using ProMax process simulation software to model and analyse and inform the hydrogen removal and compression plant concepts outlined above and deliver key technical performance parameters.

The final outputs from this work are include in Appendix A.3.0.

5.0 COST ESTIMATE REPORT

A capital cost estimate for the proposed CO_2 treatment and compression plant, including installation, was undertaken by SNC-Lavalin based on a Major Equipment List supplied by PEL and budget estimates obtained by PEL from third-party suppliers of the CO2 drying, compression and cooling plant.

The cost estimate prepared using the documents provide and AACEI estimating techniques shows a total capital cost of £29.36 million. The estimate includes risk and contingencies in accordance with SNC-Lavalin recent experience with contracts, however no detailed uncertainty analysis has been carried out.

The summary breakdown of the cost estimate for the WP3 scope can be seen in Table 5.1.

Table 5.1: Cost Estimate Summary

CLIENT:	Progressive Energy	
PROJECT:	CF Fertiliser remnant CO2 Collection	**Project Summary**
LOCATION:	CF Fertiliser	
Project NO.:	-	

CF Fertiliser remnant CO2 Collection		Equipment- Incs Packages, ie, Sub-Contact Equip	Materials	Labour	Subcontract- Incs. Buildings & Site Enabling	Licensor Fees, Mgnt, Engineering (Excl Equipment)	Contractor Soft Costs	Total
000	Site Preparation, Enabling, and Facilities - A1	-	-	123,263.26	3,243,770.11	-	324,377.01	3,691,410.39
100	Part 1 : Additional Stripper Tower (AST)	2,368,507.84	86,270.53	904,518.41	-	-	604,206.35	3,963,503.13
200	Part 2 New CO2 Pipe and Blower up to new Compressor Facility	2,837,254.39	100,722.53	1,036,931.36	-	-	780,253.47	4,755,161.75
300	Part 3 : New CO2 Compressor Facility	6,086,497.50	216,070.66	2,131,182.20	857,550.00	-	1,652,512.49	10,943,812.85
400	Part 4 : CO2 Compressor Water Coolers	107,249.50	3,807.36	39,856.13	-	-	36,183.94	187,096.93
500	Part 5 : New CO2 Dryers	567,000.00	20,652.41	222,109.05	-	-	194,154.00	1,003,915.46
600	Part 6 High Pressure CO2 piping	-	24,737.36	1,402.21	-	-	184.21	26,323.78
700	Part 7: CO2 Metering Equipment	808,701.79	37,200.28	320,227.02	-	-	231,395.76	1,397,524.85
	Total Base Cost	12,775,211.02	489,461.13	4,779,489.65	4,101,320.11	-	3,823,267.23	25,968,749.14
Risk and Contingency P80								
7.3%	Risk P80							1,895,718.69
5.8%	Contingency P80							1,498,396.83
Total								**29,362,864.65**

6.0 NEW PLANT DESCRIPTION AND LAYOUT

Figure 6.1 shows a layout drawing of the proposed additional plant. The original ammonia plant is shown in black and the existing CO_2 pipes in green. New CO_2 pipes, compressors, driers etc are shown in purple, and the location of the new tower in red. Condensate return pipes are shown in blue.

It is planned that the new column will utilise an existing concrete base and foundation, left following the removal of a redundant column. Not only will this minimise waste, but it will minimise the amount of work that needs to be carried out on site, saving money and reducing possible plant down-time. The suitability of this base will be confirmed during FEED.

New pipes will connect the existing expander to a dispersion tray approximately ⅔ of the way up the new column, allowing the rich amine solution to flow evenly across the random packing beneath. The lean amine will exit from the base of the column and new pipes will connect it via an extraction pump to the existing pipes to the present stripping tower. New pipes from the top of the new column will take the hydrogen/CO_2 mixture to the site fuel gas system.

The existing vent at the top of the stripper tower will be removed and replaced with a pressure relief system, to protect the column against overpressure in the event of a blower trip or other operational event. This would vent the entire CO_2 flow, but would be seen as a very rare situation.

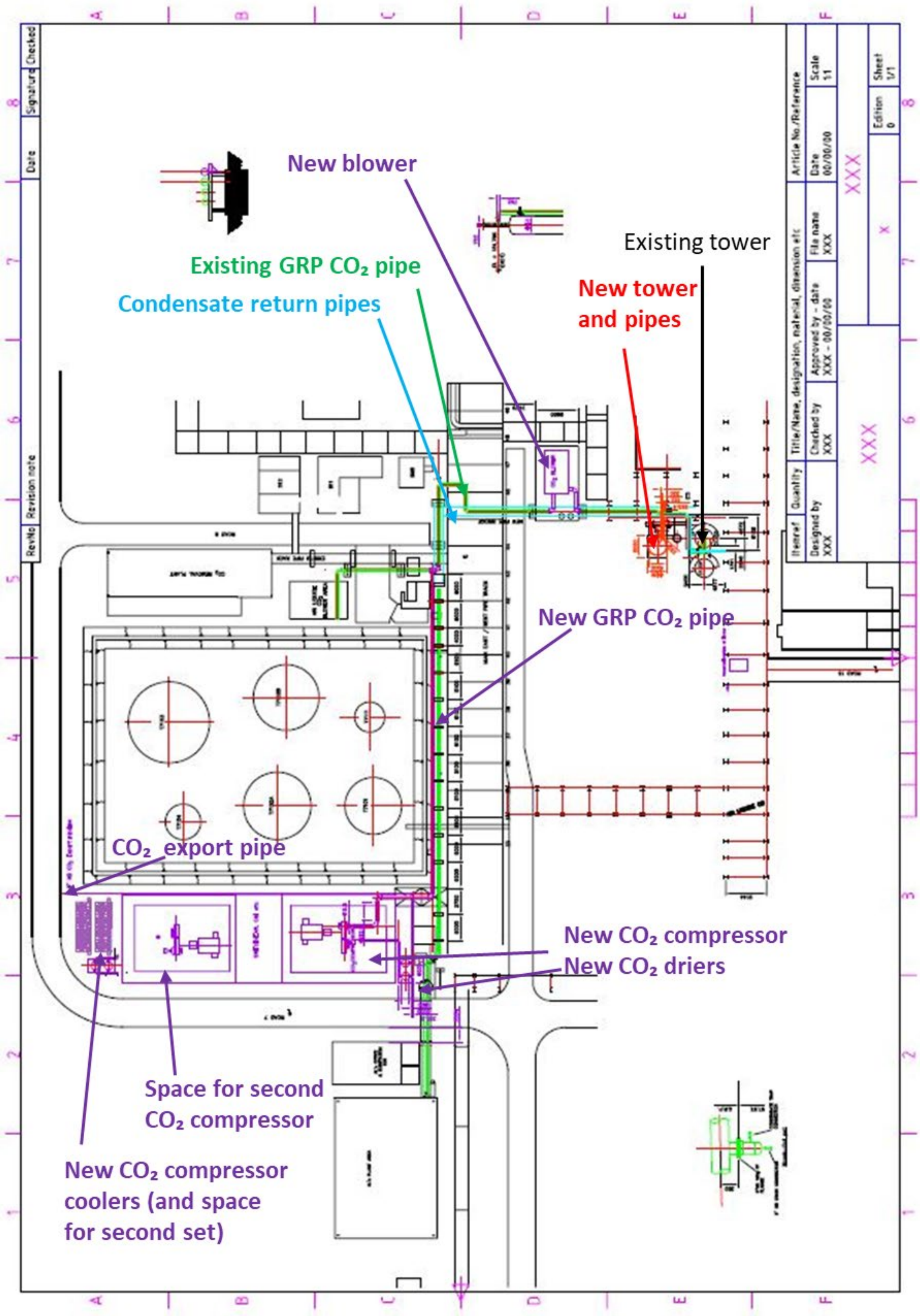
The existing 30" NB GRP pipelines are suitable for the full CO_2 flowrates and pressures. Using these will minimise the site work that would have been incurred providing access scaffolding, attaching new weldments and replacing the existing arrangements. A break-in to the existing 30" NB pipes will be made to include the blower, again, using an existing concrete plinth (subject to its suitability being confirmed during FEED). The blower controls will ensure that existing pressure conditions at the top of the tower are unchanged, ensuring plant operational parameters are unaffected by the modifications.

A new section of 30" GRP pipe will take CO_2 not required by the third party to the west end of the site where it will be compressed and dried before exporting it from the site. Heat generated during the compression will be removed by low plume hybrid cooling towers at the north of the site. Space has been allocated for a second compressor, drier and coolers to export the balance of the CO_2 in the event that there is no longer third-party offtake of CO_2.

Consideration has been given to constructability, and it is believed that thoughtful use of mobile cranes and out-of-outage works can be used to install the additional equipment without affecting the critical path of a routine shut-down of the plant.

An overview of the initial proposed site location is shown in Appendix A.3.0 and the final proposed site location is shown in Appendix A.4.0.

Figure 6.1: Drawing of layout of proposed additional equipment



7.0 CONCLUSIONS

The purpose of this Work Package 3 Pre-FEED study is to analyse CF's ammonia plant CO_2 capture system at Ince and identify and develop an associated compression scheme for the excess CO_2 in sufficient detail to confirm deliverability of the concept and provide engineering information to enable estimation of CAPEX costs.

The site currently emits a total of about 700,000 of CO_2 per annum, two thirds of which is captured as part of the production process. It is the largest single separated CO_2 source in the North West and represents a significant opportunity for CF to deliver business benefits by minimising their carbon cost exposure as well as help underpin the development and delivery of an industrial CO_2 capture network for the region.

An optioneering exercise was undertaken by the WP3 study team to determine the optimal techno/economic solutions for the capture and transportation of excess CO_2 from the site. This process included an initial workshop with CF at the site followed by consideration of the potential options and concepts based on the outcome of the analysing the information and data gathered.

Key conclusions and outcomes of the WP3 study work detailed in the pre-FEED Report are:

- Agreement by all stakeholders that capture and compression of the excess CO_2 is feasible and that the proposed single blower and compressor concept (with follow on compressor for additional capacity if required) should form the basis of the proposed scheme;
- Confirmation that 330,000 tonnes of surplus CO_2 per annum is typically available from the plant;
- Confirmation that existing liquefaction plant is fully utilised and unavailable for the excess CO_2 export duty;
- Agreement that the overall compression system design conditions should be based on a 50mbarg suction pressure at 70°C and 39barg discharge pressure at 20°C;
- Confirmation that there is enough land on the CF site to house the new flash vessel, blower and compressor(s) and that there are adequate utilities and services to meet projected needs;
- Confirmation that no planning or permitting constraints are foreseen;
- Confirmation that a maximum excess CO_2 stream hydrogen level <0.75vol% is achievable in a cost-effective manner utilising an additional flash vessel in the existing capture train;
- Agreement on the use of proven technology that is readily available from established manufacturers and suppliers to assist in de-risking the project;
- Confirmation that there are no operability issues foreseen with the proposed compression solution;

- Based on the detailed MEL an estimated capital cost of £29.36m million (including risk and contingency);
- Confirmation that the Pre-FEED Report forms a good basis for the next phase of FEED work.

In summary, following a detailed study with key stakeholders a single option solution has been identified and confirmed as the most cost-effective, timely and least risk route for CF to capture and export its excess CO_2 production to an onshore transportation network.

APPENDICES

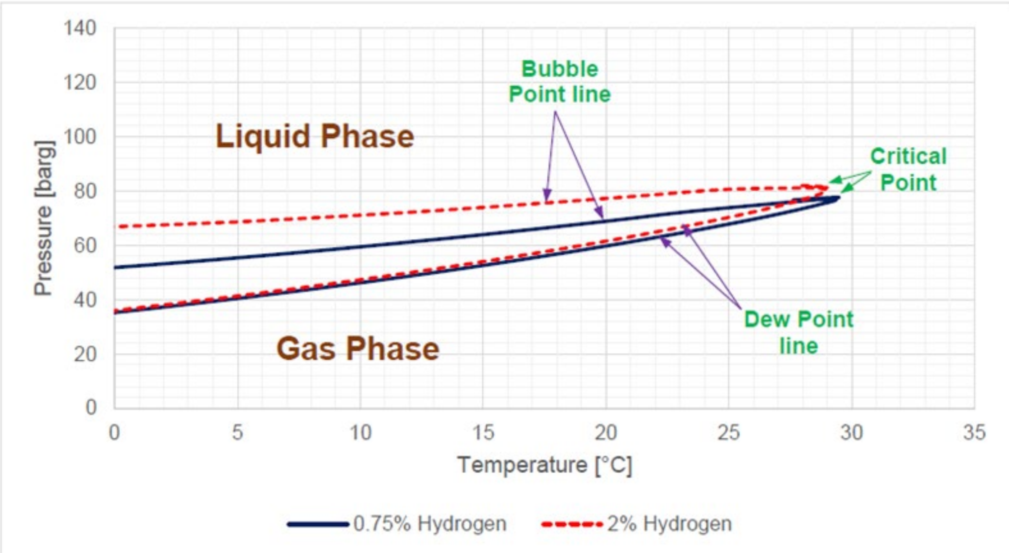
A.1.0 IMPACT OF CO_2 STREAM

The two species of most concern are the hydrogen content and the water. This appendix explains the nature of the problems.

A.1.1 IMPACT OF HYDROGEN CONTENT

The higher hydrogen content affects the effective operating window for the pipeline because it results in a larger two-phase area, where the thermodynamic properties of the CO_2 stream cannot be predicted using modern computer modelling techniques, and should therefore be avoided. This effect is shown in Figure A1.1.

Figure A1.1: Phase diagram for CO_2 with 2vol% and 0.75vol% H_2

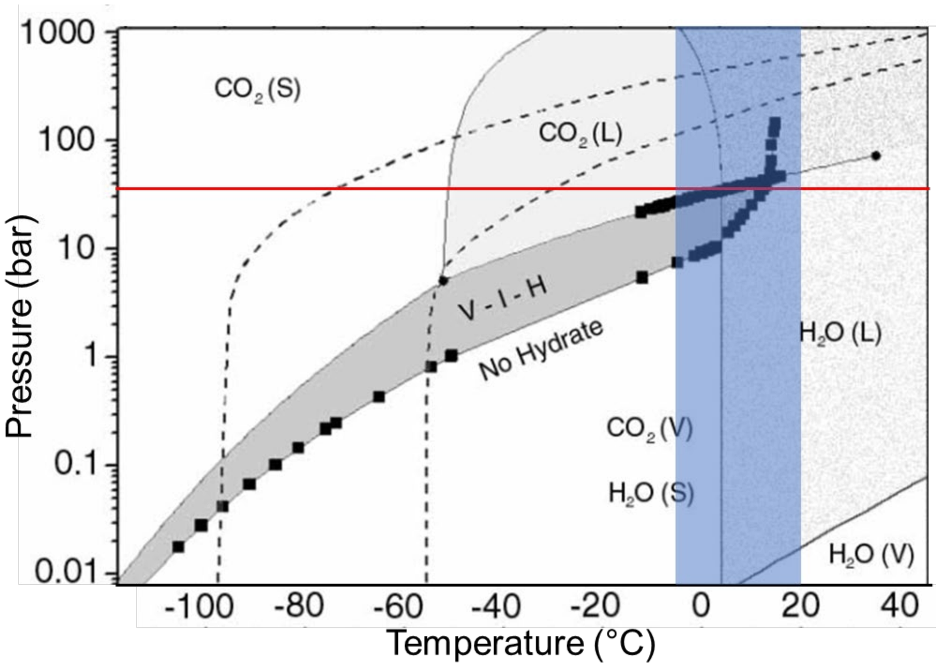


A.1.2 IMPACT OF WATER CONTENT

The water content needs to be kept low because the presence of water amplifies the changes that result from the presence of other impurities in the CO_2, and increases the possibility of hydrate formation at low temperatures. Carbon dioxide hydrate (or carbon dioxide clathrate) is a snow-like crystalline substance composed of water ice and carbon dioxide. It normally is a Type I gas clathrate. The problem is that, once formed, hydrates disperse slowly, and can be carried along pipelines with the flow of the CO_2 stream, with the potential that the solid could block safety valve penetrations or prevent ball valves from closing fully.

A hydrate formation graph[7] for pure CO_2 is shown as Figure A1.2. In this figure, the H_2O phase boundaries are only guides to the eye, the black squares show experimental results. The abbreviations are as follows: L - liquid, V - vapour, S - solid, I - water ice, H - hydrate. The operational conditions of the CO_2 transportation are indicated by the red line (at 34bar) and the blue rectangle (temperature range).

Figure A1.2: Pure CO_2 hydrate formation diagram



It may be seen that there is significant potential for the formation of hydrates within this operational window, for pressures as low as about 6.5bar. To avoid the potential operational problems, the water content is specified as being below the level at which there is "free water".

Hydrate formation is a statistical phenomenon. Experimental work and modelling has been carried out specifically to establish the hydrate stability zone[8], outside of which formation will not take place in pure carbon dioxide. The objective has been to establish the conditions under which hydrates can form under different conditions of temperature and pressure for a number of specific contents of moisture within pure CO_2. Figure A1.3 is a representation of the hydrate/ice stability zones (regions to the left of red lines) for pure CO_2 with a moisture content of 250 ppmv. The grey dotted line and its extensions toward -50°C and 0°C represent the hydrate/ice stability zones in saturated conditions or

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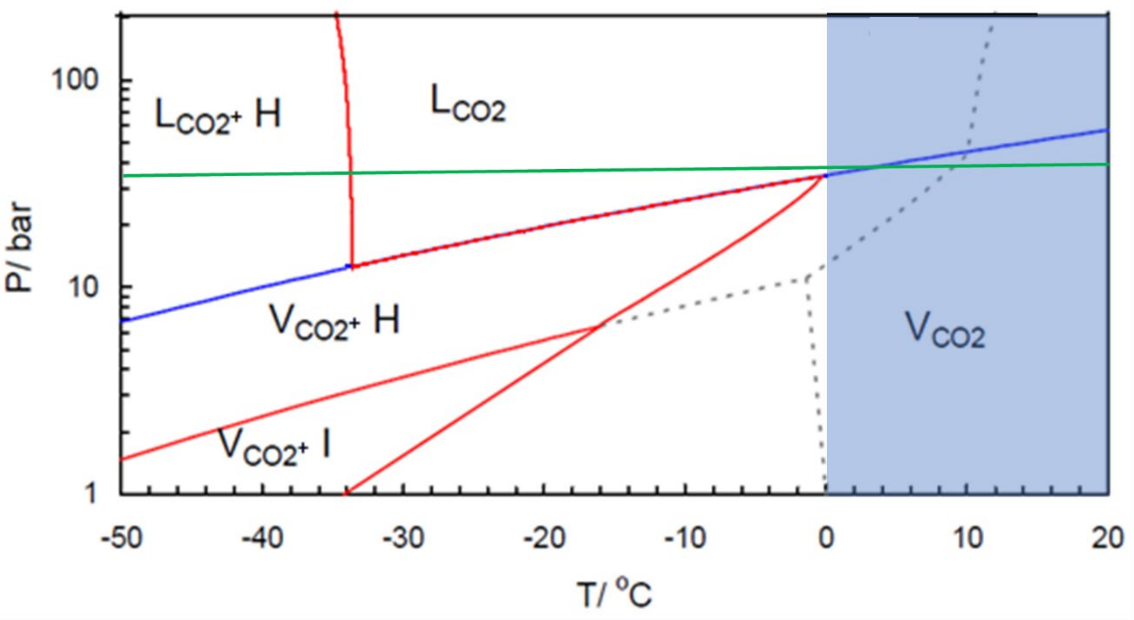
[7] Extracted from "Physical processes of CO2 hydrate formation and decomposition at conditions relevant to Mars", G Y Genov, Ph.D. Thesis, University of Göttingen, 2005

[8] SPE 123778, "Effect of Common Impurities on the Phase Behaviour of Carbon Dioxide Rich Systems: Minimizing the Risk of Hydrate Formation and Two-Phase Flow", A Chapoy, R Burgass, B Tohidi (Hydrafact Ltd & Centre for Gas Hydrate Research, Institute of Petroleum Engineering, Heriot-Watt University), and J M Austell, C Eickhoff (Progressive Energy Ltd). Society of Petroleum Engineers, 2009

the presence of free water. Hydrate formation is possible in the area bounded by V_{CO2}+H and left up to the grey dotted line, and the conditions in the HyNet CO_2 pipelines are shown by the green line (35bar pressure) and the blue rectangle (temperature).

Figure A1.3: Hydrate/ice stability zones for pure CO_2 with a moisture content of 250 ppmv



Key to symbols:

CO_2 (S): Solid CO_2	CO_2(L): Liquid CO_2
CO_2(V): CO_2 Vapour	H_2O(V): Water vapour
H_2O(S): Solid water (ice)	H_2O(L): Liquid water
V-I-H: Vapour-ice-hydrate envelope	CO_2 (S/C): CO_2 in the supercritical phase

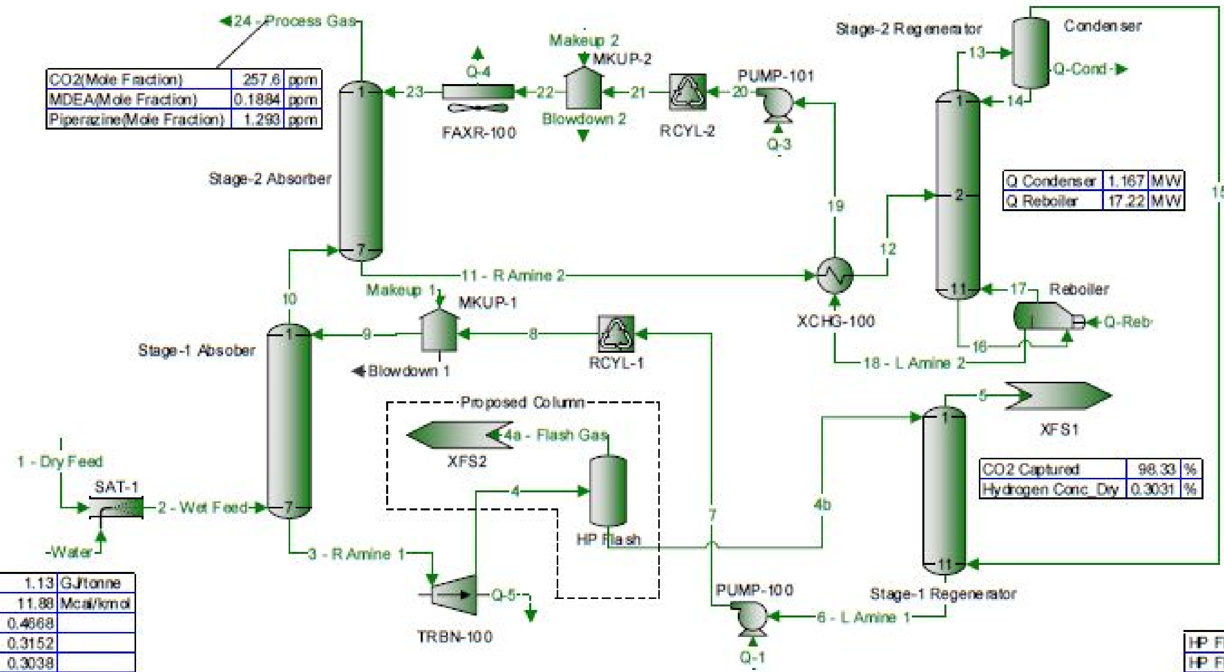
Whilst the SPE 123778 research indicated hydrate formation is considered unlikely to occur below 200 – 250ppmv, a more conservative approach was adopted by both the National Grid Carbon[9] and Longannet[10] projects, partly to provide confidence for safe operation, and partly because the presence of water enhances the potential for other potentially damaging reactions to take place, e.g. with SO_2 and NOx. This standard has been adopted by the HyNet project, and is consistent with BS ISO 27913[11].

[9] NGC/SP/PIP/25 "National Grid Carbon Specification for Carbon Dioxide Quality requirements for Pipeline Transportation", 2014

[10] Document no 09 / 2520 / 0002, Rev L (18/7/10), assumptions 76 and 92 "Register of Design Assumptions FEED Project Development", Rhead Group

[11] ISO 27913 "Carbon dioxide capture, transportation and geological storage — Pipeline transportation systems", 2016

A.2.0 PFD & HMB



CO2(Mole Fraction)	257.6	ppm
MDEA(Mole Fraction)	0.1884	ppm
Piperazine(Mole Fraction)	1.293	ppm

Q Condenser	1.167	MW
Q Reboiler	17.22	MW

CO2 Captured	98.33	%
Hydrogen Conc_Dry	0.3031	%

Regeneration Energy	1.13	GJ/tonne
CF Regen Quote	11.88	Mcal/kmol
Rich Loading 1	0.4668	
Lean Loading 1	0.3152	
Rich Loading 2	0.3038	
Lean Loading 2	0.01082	

HP Flash Height	23.23	m
HP Flash Diameter	3.81	m
HP Flash Mass	43.52	tonne

Names	Units	2 - Wet Feed	3 - R Amine 1	4	4a - Flash Gas	6 - L Amine 1	9	10	11 - R Amine 2	12	18 - L Amine 2	19	23	24 - Process Gas	13	5
Temperature	°C	70.2	86.09	86.01	85.94	76.01	76.5	77.82	73.89	100	112.8	87.56	42	42.11	93.38	73.83
Pressure	barg	23	23	6.939	5.5	0.15	24	22.8	22.8	22.8	0.4	0.4	24	22.5	0.2	0.05
Mass Flow	kg/s	30.01	516.5	516.5	0.2803	504.5	504.9	18.37	82.81	82.81	76.43	76.43	78.53	14.09	6.883	18.06
Molar Flow	kmol/h	7104	6.491e+04	6.491e+04	35.46	6.389e+04	6.395e+04	6143	1.041e+04	1.041e+04	9584	9584	1e+04	5739	922.8	1812
Hydrogen(Mole Fraction)	%	59.64	0.0184	0.0184	29.16	5.689e-06	5.683e-06	68.78	0.02106	0.02106	0	0	0	73.57	0.2374	0.2092
Nitrogen(Mole Fraction)	%	20.25	0.003836	0.003836	6.408	7.828e-07	7.819e-07	23.38	0.004549	0.004549	0	0	0	25.01	0.05129	0.03812
CO2(Mole Fraction)	%	17.85	4.513	4.513	55.49	3.096	3.093	5.149	3.137	3.137	0.1214	0.1214	0.1163	0.02576	34.12	68.78
Methane(Mole Fraction)	%	0.4042	0.0002261	0.0002261	0.3219	1.631e-07	1.629e-07	0.4651	0.0002901	0.0002901	0	0	0	0.4973	0.003271	0.003461
Argon(Mole Fraction)	%	0.2662	8.83e-05	8.83e-05	0.1384	3.41e-08	3.406e-08	0.3069	0.0001091	0.0001091	0	0	0	0.3283	0.00123	0.001081
CO(Mole Fraction)	%	0.1873	4.759e-05	4.759e-05	0.07717	1.349e-08	1.347e-08	0.2161	5.746e-05	5.746e-05	0	0	0	0.2312	0.0006479	0.0005239
H2O(Mole Fraction)	%	1.407	85.8	85.8	8.403	87.08	87.09	1.705	86.51	86.51	88.66	88.66	89.14	0.3308	65.59	30.96
MDEA(Mole Fraction)	%	0	8.693	8.693	0.001135	8.833	8.824	0.0002335	8.436	8.436	9.159	9.159	8.776	1.884e-05	0.0001513	0.003406
Piperazine(Mole Fraction)	%	0	0.9751	0.9751	4.032e-05	0.9908	0.9898	1.445e-05	1.892	1.892	2.055	2.055	1.969	0.0001293	0.0004104	0.0002272

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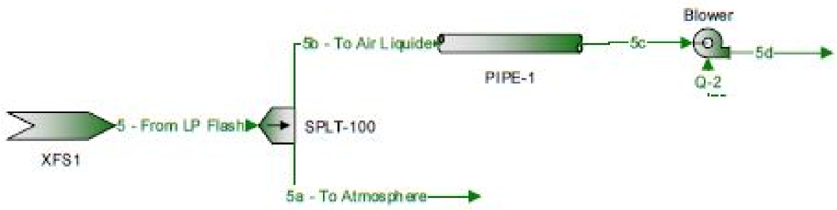
Page 1 (of 3)

Progressive energy



Names	Units	5 - From LP Flash	5a - To Atmosphere	5b - To Air Liquide	5c	5d
Temperature	°C	73.62	73.62	73.62	74.09	111
Pressure	barg	0.05	0.05	0.05	0.05534	0.5*
Mass Flow	kg/s	18.36	12.85	5.507	5.507	5.507
Molar Flow	kmol/h	1852	1296	555.5	555.5	555.5
CO2(Mole Fraction)	%	68.38	68.38	68.38	68.38	68.38
H2O(Mole Fraction)	%	30.67	30.67	30.67	30.67	30.67
Hydrogen(Mole Fraction)	%	0.7626	0.7626	0.7626	0.7626	0.7626
Nitrogen(Mole Fraction)	%	0.1599	0.1599	0.1599	0.1599	0.1599
Methane(Mole Fraction)	ppm	95.38	95.38	95.38	95.38	95.38
Argon(Mole Fraction)	ppm	37.07	37.07	37.07	37.07	37.07
CO(Mole Fraction)	ppm	19.9	19.9	19.9	19.9	19.9
MDEA(Mole Fraction)	ppm	33.49	33.49	33.49	33.49	33.49
Piperazine(Mole Fraction)	ppm	2.214	2.214	2.214	2.214	2.214

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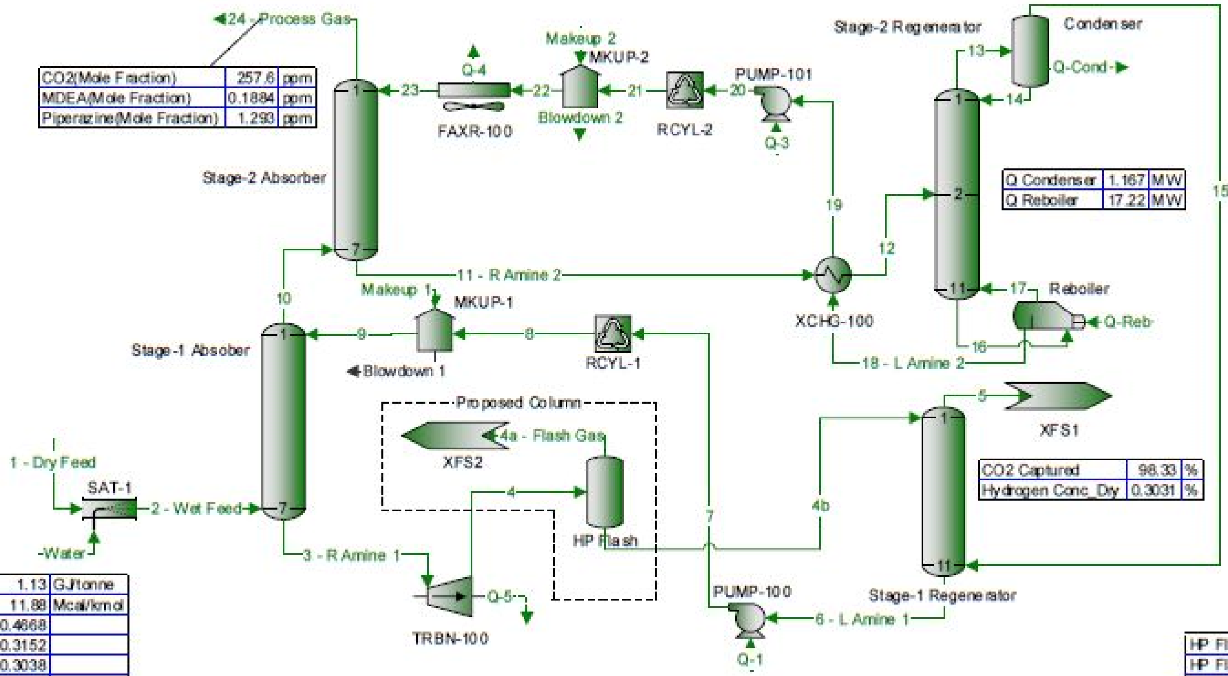
Page 2 (of 2)

Progressive energy



Regeneration Energy	1.13	GJ/tonne
CF Regen Quote	11.88	Mcal/kmol
Rich Loading 1	0.4668	
Lean Loading 1	0.3152	
Rich Loading 2	0.3038	
Lean Loading 2	0.01082	

HP Flash Height	23.23	m
HP Flash Diameter	3.81	m
HP Flash Mass	43.52	tonne

Names	Units	2 - Wet Feed	3 - R Amine 1	4	4a - Flash Gas	6 - L Amine 1	9	10	11 - R Amine 2	12	18 - L Amine 2	19	23	24 - Process Gas	13	5
Temperature	°C	70.2	86.09	86.01	85.94	76.01	76.5	77.82	73.89	100	112.8	87.56	42	42.11	93.38	73.83
Pressure	barg	23	23	6.939	5.5	0.15	24	22.8	22.8	22.8	0.4	0.4	24	22.5	0.2	0.05
Mass Flow	kg/s	30.01	516.5	516.5	0.2803	504.5	504.9	18.37	82.81	82.81	76.43	76.43	78.53	14.09	6.883	18.06
Molar Flow	kmol/h	7104	6.491e+04	6.491e+04	35.46	6.389e+04	6.395e+04	6143	1.041e+04	1.041e+04	9584	9584	1e+04	5739	922.8	1812
Hydrogen(Mole Fraction)	%	59.64	0.0184	0.0184	29.16	5.689e-06	5.683e-06	68.78	0.02106	0.02106	0	0	0	73.57	0.2374	0.2092
Nitrogen(Mole Fraction)	%	20.25	0.003836	0.003836	6.408	7.828e-07	7.819e-07	23.38	0.004549	0.004549	0	0	0	25.01	0.05129	0.03812
CO2(Mole Fraction)	%	17.85	4.513	4.513	55.49	3.096	3.093	5.149	3.137	3.137	0.1214	0.1214	0.1163	0.02576	34.12	68.78
Methane(Mole Fraction)	%	0.4042	0.0002261	0.0002261	0.3219	1.631e-07	1.629e-07	0.4651	0.0002901	0.0002901	0	0	0	0.4973	0.003271	0.003461
Argon(Mole Fraction)	%	0.2662	8.83e-05	8.83e-05	0.1384	3.41e-08	3.406e-08	0.3069	0.0001091	0.0001091	0	0	0	0.3283	0.00123	0.001081
CO(Mole Fraction)	%	0.1873	4.759e-05	4.759e-05	0.07717	1.349e-08	1.347e-08	0.2161	5.746e-06	5.746e-06	0	0	0	0.2312	0.0006479	0.0005239
H2O(Mole Fraction)	%	1.407	85.8	85.8	8.403	87.08	87.09	1.705	86.51	86.51	88.66	88.66	89.14	0.3308	65.59	30.96
MDEA(Mole Fraction)	%	0	8.693	8.693	0.001135	8.833	8.824	0.0002335	8.436	8.436	9.159	9.159	8.776	1.884e-05	0.0001513	0.003406
Piperazine(Mole Fraction)	%	0	0.9751	0.9751	4.032e-05	0.9908	0.9898	1.445e-05	1.892	1.892	2.055	2.055	1.969	0.0001293	0.0004104	0.0002272

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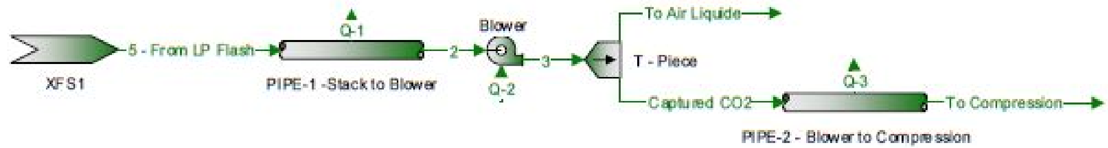
Page 1 (of 3)

Progressive energy



Q Blower	1.328	MW

Names	Units	5 - From LP Flash	2	3	To Air Liquide	Captured CO2	To Compression
Temperature	°C	73.83	71.05	134.8	134.8	134.8	109.7
Pressure	barg	0.05	0.04629	1*	1	1	0.9961
Mass Flow	kg/s	18.06	18.06	18.06	5.417	12.64	12.64
H2O(Mass Flow)	kg/s	2.808	2.808	2.808	0.8423	1.965	1.965
Molar Flow	kmol/h	1812	1812	1812	543.7	1269	1269
CO2(Mole Fraction)	%	68.78	68.78	68.78	68.78	68.78	68.78
H2O(Mole Fraction)	%	30.96	30.96	30.96	30.96	30.96	30.96
Hydrogen(Mole Fraction)	%	0.2092	0.2092	0.2092	0.2092	0.2092	0.2092
Nitrogen(Mole Fraction)	%	0.03812	0.03812	0.03812	0.03812	0.03812	0.03812
Methane(Mole Fraction)	ppm	34.61	34.61	34.61	34.61	34.61	34.61
Argon(Mole Fraction)	ppm	10.81	10.81	10.81	10.81	10.81	10.81
CO(Mole Fraction)	ppm	5.239	5.239	5.239	5.239	5.239	5.239
MDEA(Mole Fraction)	ppm	34.06	34.06	34.06	34.06	34.06	34.06
Piperazine(Mole Fraction)	ppm	2.272	2.272	2.272	2.272	2.272	2.272

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Page 2 (of 3)

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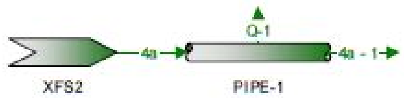
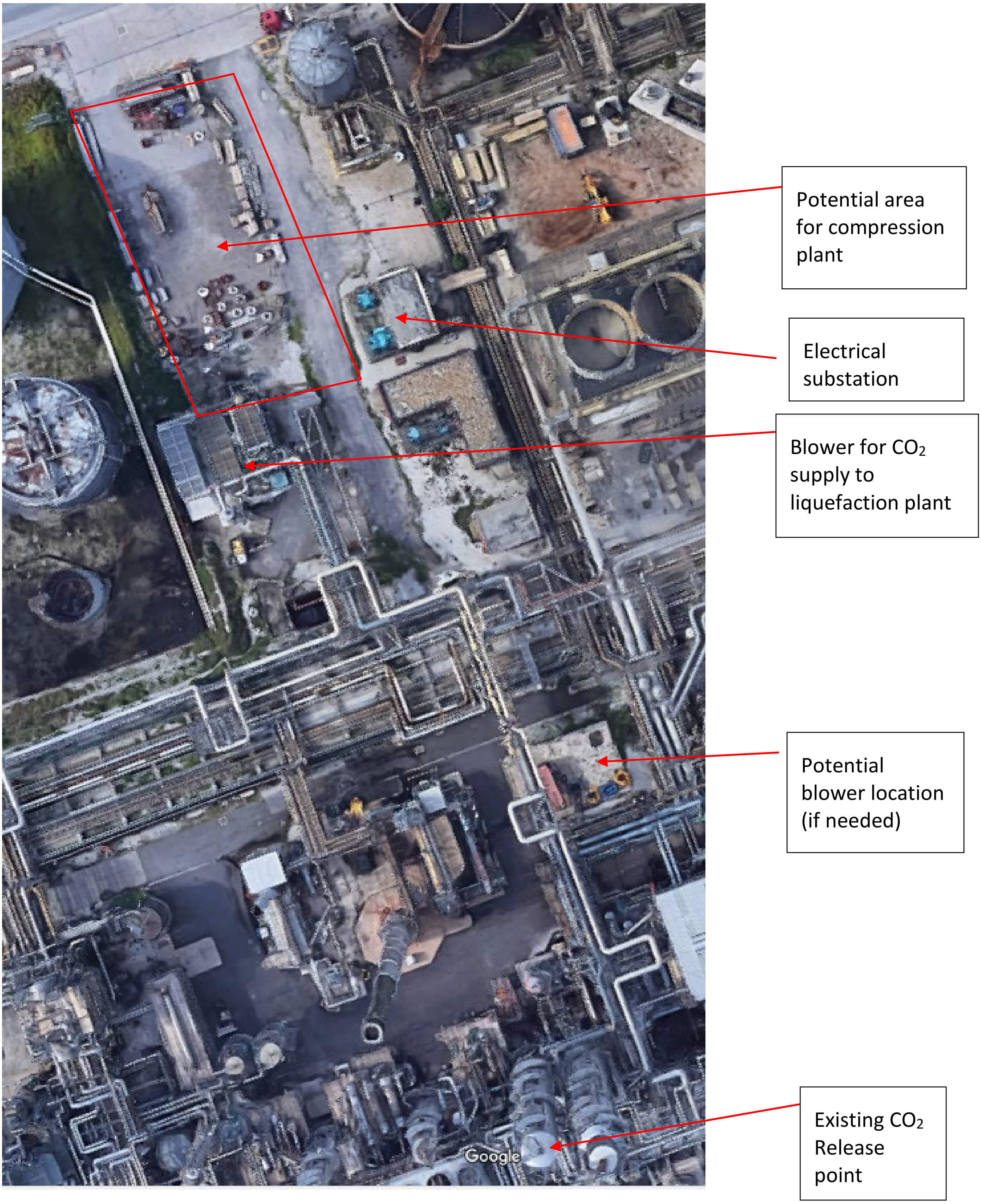


Names	Units	4a	4a - 1
Temperature	°C	85.94	64.28
Pressure	barg	5.5	5.497
Mass Flow	kg/s	0.2803	0.2803
Molar Flow	kmol/h	35.46	35.46
Hydrogen(Mole Fraction)	%	29.16	29.16
CO2(Mole Fraction)	%	55.49	55.49
H2O(Mole Fraction)	%	8.403	8.403
Nitrogen(Mole Fraction)	%	6.408	6.408
Methane(Mole Fraction)	%	0.3219	0.3219
Argon(Mole Fraction)	%	0.1384	0.1384
CO(Mole Fraction)	ppm	771.7	771.7
MDEA(Mole Fraction)	ppm	11.35	11.35
Piperazine(Mole Fraction)	ppm	0.4032	0.4032

A.3.0 INITAL SITE LOCATION OVERVIEW



A.4.0 FINAL SITE LOCATION OVERVIEW