TIGRE TECHNOLOGIES LIMITED CS362

Feasibility Study: Integration of CCUS technology with a 200MW OCGT TiGRE™ Project located in the UK Southern North Sea

KKD2: Basis of Design

Executive summary

The feasibility study has assessed whether applying CCUS to a TiGRE project will provide the lowest cost of energy (LCOE) with CO2 captured and sequestered while maintaining flexible and dispatchable power generation, relative to any other gas power generation CCUS option currently under consideration within the UK. A TiGRE™ project offers full and in situ vertical integration of the gas production, power production, CO2 capture, and sequestration activities.

The study has shown that a TiGRE™ gas to wires project does provide the lowest cost option to capture and sequester carbon while maintaining flexible and dispatchable power generation, relative to any other gas power generation CCUS option believed to be currently under consideration within the UK. TTL considered 3 possible options to capture, separate and sequester CO2:

Option 1: Chemical separation

Option 2: Post-combustion Cryogenic separation

Option 3: Oxyfuel generation

Option1 has been considered unviable when integrated into a TiGRE project and in an offshore environment due to its substantial weight and footprint, costly operations, low level of efficiencies and high latency of the overall system which does not lend itself to dispatchable and flexible power generation. Both Options 2 and 3 are considered both technically and commercially viable solutions and have been thoroughly assessed. Oxyfuel Power plants have a lower LCOE than a TiGRE™ OCGT power plant at load factors above 40%. This would suggest a TiGRE Oxyfuel power plant would not require CO2 subsidies to be competitive in the merchant power market for peaking plant. This suggests that the Oxyfuel concept has the highest investment returns even at relatively low load factors.

KKDs:

1. KKD1: The Feasibility Study Report and Recommendations [this report]
2. KKD2: The Basis of Design

kKD2:

This Report contains the finalised Basis of Design resulting from the work undertaken by the Feasibility Study. Any follow-on work will be the subject of additional work scope.

Rob Hastings, CEO

March 16th 2020

CCUS Feasibility Study

Basis of Design

CS362_CCUS FEASIBILITY STUDY

Author: TIGRE Technologies Limited

Date: 13th March 2020

Rev	Purpose	List of Updated/Modified Sections
1.0	BEIS feasibility Study Milestone 1	Initial Issue
2.0	BEIS feasibility Study Milestone 3	All Sections

CONTENTS

Glossary of terms

Term	Description
BoD	Basis of Design
CAPEX	Capital Expenditure
ChemSep	Chemical Separation
CCGT	Combined Cycle Gas Turbine
CCUS	Carbon Capture and Underground Storage
CO2	Carbon dioxide
CVP	Commercial Value Proposition
EU ETS	European Union Energy Trading Scheme
EVP	Economic Value Proposition
FEED	Front-end Engineering Design
GIIP	Gas Initially In Place. An estimate of Reservoir Gas at initial conditions prior to the start of any production
HAZID	Hazard Identification Study
HYSYS	A process engineering modelling propriety system; owned by Aspen Tech
H2O	Water
IRR	Internal Rate of Return
ITL	Indigo TiGRE Limted
LCOE	Levelised Cost of Energy
OCGT	Open Cycle Gas Turbine
OFGT	Oxyfuel Gas Turbine
O&M	Operations and Maintenance
OPEX	Operational Expenditure
Oxyfuel	The process of burning a fuel using pure oxygen instead of air as the primary oxidant
SEALS	Sequestered Emissions at Locational Source
SNS	Southern North Sea
TTL	TiGRE Technologies Ltd.
TiGRE	Transition to integrated Gas and Renewable Energy
TiGRESS	Transition to integrated Gas and Renewable Energy Simulation System

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1 INTRODUCTION

1.1 Background

TiGRE™ Technologies Ltd (TTL) has agreed with BEIS grant support to investigate the feasibility of installing pre or post combustion CCUS facility at an offshore installation to be integrated with an Open Cycle Gas Turbine (OCGT) generation station. The installations are expected to be co-located with associated offshore natural gas production and geological gas storage sites in the Southern North Sea of the UKCS. The concept is called TiGRE™ SEALS (Transition to integrated Gas and Renewable Energy, Sequestered Emissions at Locational Source).

1.1.1 The TiGRE™ Concept

The TiGRE™ (**Transition to integrated Gas and Renewable Energy)** concept involves the development and deployment of projects comprising gas-fired power station facilities integrated with both existing late-life gas fields to utilise the gas at source and avoid gas transportation and processing costs, and with existing transmission infrastructure associated with offshore windfarms. Key components of TiGRE™ are:

- **Mid to late-life gas production assets** seeking production cost reduction opportunities to extend production life.
- **Construction of proven technology of aeroderivative Open Cycle Gas Turbine (OCGT) generators** located offshore either on or adjacent to gas production and close to an offshore windfarm substation.
- **Exported through existing offshore wind farm transmission infrastructure (OFTO)** utilising up to 50% spare capacity available from intermittency of wind generation.

The exported electricity entering the national grid would come from a combination of gas and offshore wind: **secure, greener, reliable power**. The TiGRE™ concept is shown in Figure 1.

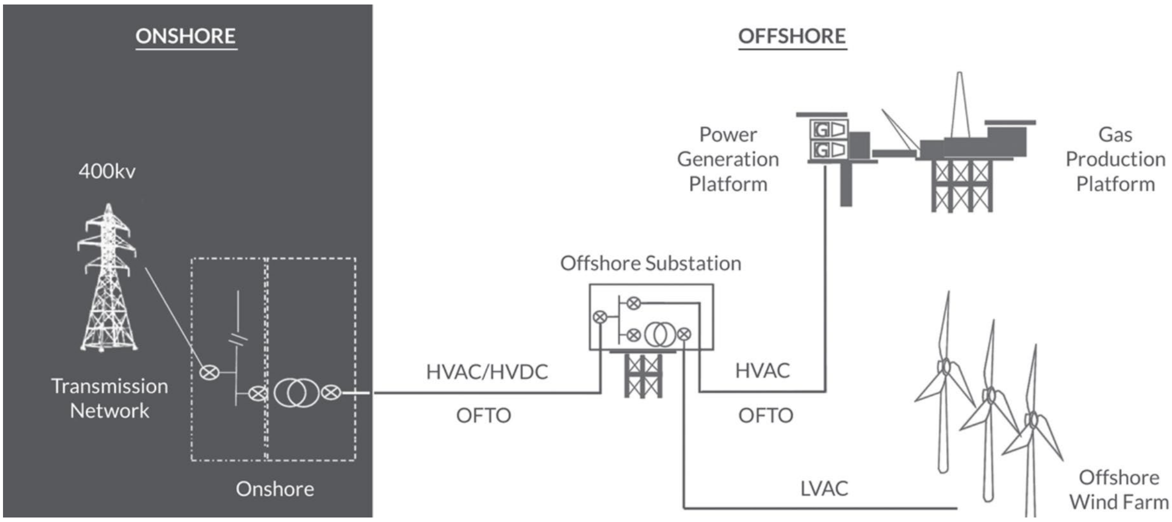

Figure 1: TiGRE™ Concept High level Schematic Diagram

1.1.2 TiGRE™ SEALS Concept Overview

The TiGRE™ Group believe that TiGRE™ SEALS provides the overall lowest cost option to capture and sequester CO2 when deployed in conjunction with an open cycle gas turbine TiGRE™ project in the UK Southern North Sea. The concept offers in situ vertical integration of the gas production, power production, CO2 capture and sequestration activities.

Figure 2 shows the complete closed-circuit hydrocarbon lifecycle management utilising TiGRE™ SEALS concept.

Extending the TiGRE™ concept to include TiGRE™ SEALS allows a new perspective for CCUS potential technologies. The key aspects to be considered when assessing Carbon Capture Technologies when applied to the TiGRE™ SEALS concept include:

1. The TiGRE™ concept is based on an OCGT delivering peak power into the grid. When online the OCGT load will vary depending upon the access to the grid that is available because a TiGRE™ project will share the capacity available in the offshore electrical transmission network with an offshore wind farm that will have preference for use of the available transmission line capacity.

2. The TiGRE™ concept is commercially viable as a standalone concept normally running in the open cycle mode (as peaking plant). The waste heat from the OCGT would be vented to the atmosphere via the OCGT exhaust stacks whereas the TiGRE™ SEALS concept has the option to utilise this available waste heat by recovering it to provide steam for process heating or electricity generation via co-generation. This is a different approach from the economics of a traditional CCGT in that any energy required to run the CCUS process on a CCGT plant is treated as a ‘parasitic load’ i.e. energy that would normally be sold as electricity and reduces the output of a typical CCGT plant.

3. Locating the TiGRE™ SEALS concept on an offshore installation has unique challenges and opportunities compared to an onshore CCUS process in that the costs of installing and operating equipment offshore are much more expensive than onshore. In an offshore environment optimising space and weight become much bigger issues than onshore.

4. Operationally the challenges associated with an offshore environment are around reducing the operational costs through reducing the manning levels and logistics required to service the offshore facility. This means simplification of process plant, reduction of rotating equipment and automation, designing to a normally unmanned mode and minimising transportation of materials and personnel where possible.

5. An opportunity for the TiGRE™ SEALS concept compared to onshore CCUS projects is that the transportation costs and challenges are reduced as the CO2 capture plant is already located offshore close to the CO2 offshore storage locations. This creates a closed circuit for the management of CO2, Figure 2. The natural gas is sourced and directly combusted in plant integrated at the offshore gas field, the CO2 is captured from the flue gases and directly sequestered down-hole into the operational gas field.

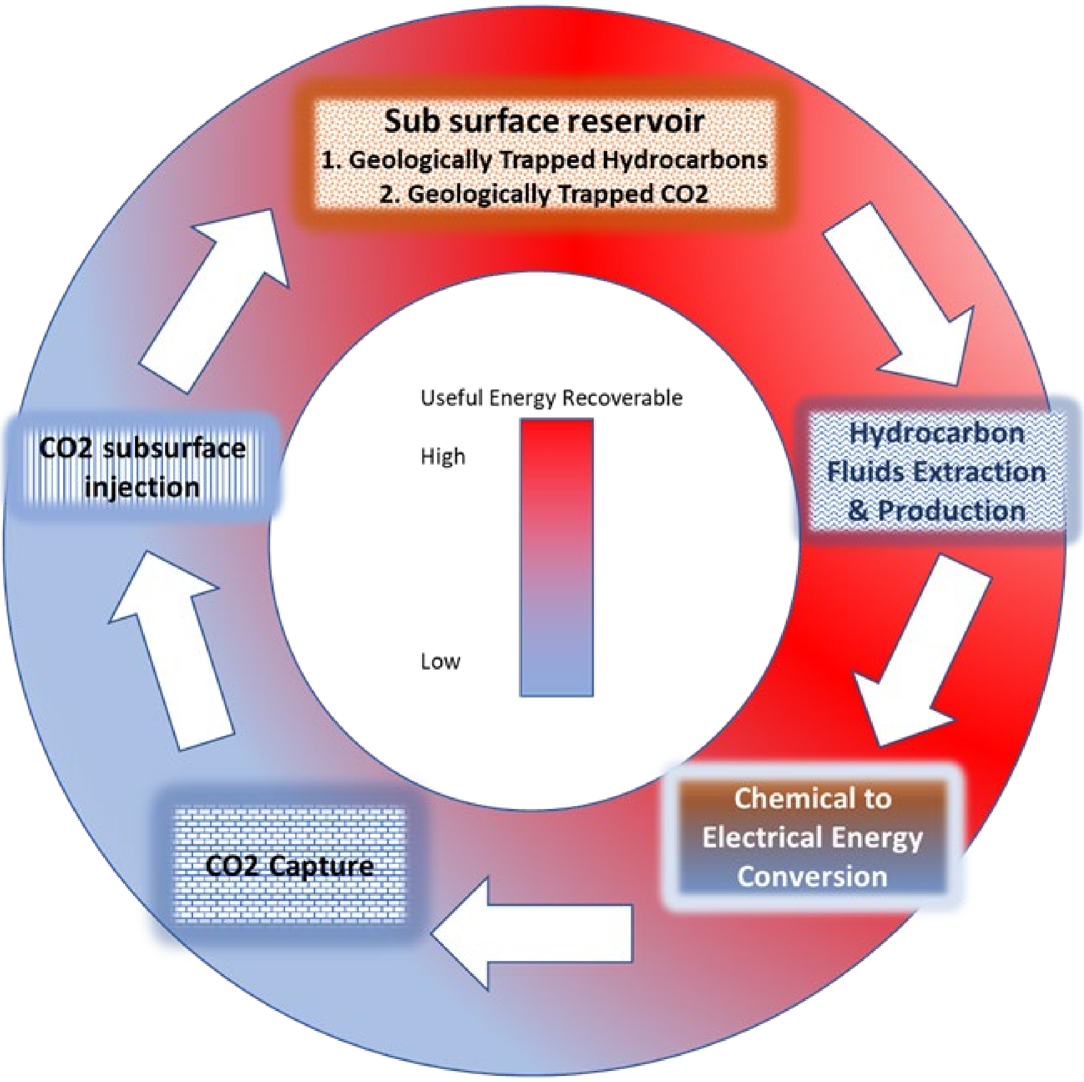

Figure 2: TiGRE^{TM} SEALS CO2 Lifecycle Diagram

1.1.3 Feasibility Study Description

The feasibility study addresses whether it is technically feasible and commercially viable to integrate the CCUS process into a TiGRE™ gas to wires project. The feasibility study has focused on the following 5 stages:

1. Understanding the necessary characteristics of required from natural gas reservoirs with respect to CO2 storage during production and under conditions produced by complete hydrocarbon lifecycle management.

2. The design modification of the TiGRE™ gas to wire concept to provide for an integrated carbon capture and storage process based on parameters of a typical TiGRE™ project under development by the TiGRE™ Group.

3. TiGRE™ plus CCUS concept optimisation focusing on LCOE for near zero carbon electricity generation within the constraints of the existing offshore gas assets and production facilities.

4. Determination of the expected CAPEX and OPEX of the additional CCUS plant required.

5. Production of report and recommendation.

The results from the feasibility study will answer the hypothesis that applying CCUS to a TiGRE™ gas to wires project will provide the least cost option (LCOE) to capture and sequester carbon from flexible and dispatchable power generation than any other CCUS option currently under consideration within the UK.

The TiGRE™ aspiration is that the application of TiGRE™ SEALS to a TiGRE™ gas to wires project will ensure that the power entering the grid will come from a combination of indigenous gas and renewable energy resources and will be greater than 92% carbon free.

1.2 Scope of the Basis of Design

The purpose of this document is to detail all base data with referring to the data source, that is required to complete the TiGRE™ CCUS feasibility study. This document will be updated once specific projects are identified and at each project phase i.e., Pre-FEED, FEED.

This document describes 3 design options to reflect the work carried out in the feasibility study, which are summarised below:

Option 1: Combined Cycle Gas Turbine Turbo generator with post-combustion CO2 Chemical Absorption processes using Amine, CO2 liquification, pumping and storage.

Option 2: Combine Cycle with enrichment processes and post-combustion Cryogenic capture of CO2 is solid phase for liquification, pumping and storage.

Option 3: Oxyfuel direct combustion and expansion through a gas turbine with H2O as supplemental working fluid to capture and store liquid CO2.

Appendices 1, 2 & 3 contains the HYSYS process flow diagrams for the above 3 options, produced as part of the Milestone 2 submission slidepack in January 2020.

1.2.1 Option 1: Combined Cycle Gas Turbine Turbo generator with post combustion CO2 chemical absorption using Amine, CO2 liquification, pumping and storage.

Concept Description

The TiGRE™ SEALS Chemical CO2 separation concept Figure 3 uses amine-based solvents to strip CO2 from the systems exhaust gasses and thereby separate the CO2 from compression and storage. Amine based CO2 capture is a relatively well understood technology and has been deployed in several configurations for gas sweating.

Process

- Natural Gas production system using existing wells and producing reservoir. Natural gas can be produced down to 1bar pressures at the production well head and compressed to pressures >60bar for injection into the gas turbine and reheat after burners.
- The primary electrical energy generation plant consists of the basic concept outlined in section 1.1.2 above defining the TiGRE™ CCGT system. The amount of exhaust gas reheat energy is lower (fuel flow rate reduced to 1kg/s) than that to achieve maximum CO2 concentrations, and there is no recycling of the exhaust gases for this concept. The objective is to achieve an overall saturation of CO2 to around 8% by mass, which was found to be the practical optimum with respect to amine volumes required through the absorption process.
- The Chemical CO2 removal consists of an absorber and regenerator process. DEAmine was selected as the working solvent based on a literature review to match the specific duty of the TiGRE™ concept. In particular, the key determining criteria relate to reducing the size of the process columns, and minimising degradation of the solvent given the cost of providing makeup solvent in the offshore location. In addition, the process by products can be reduced and therefore also reducing the overhead of sludge removal from the offshore location.
- The relatively dry CO2 product is received from the separation plant for compression and further dehydration to get it to liquid phase in preparation for injection into the reservoir through the injection well(s).
- CO2 is discharged into the same subsurface reservoir which is producing the fuel gas in dense phase which provides the necessary gravity head to permit CO2 injection. CO2 largely remains in dense phase and has the effect of increasing reservoir pressure of time which assists natural gas production through re-pressurisation of the reservoir.
- The subsequent pages show the process design for the TiGRE™ SEALS chemical separation design.

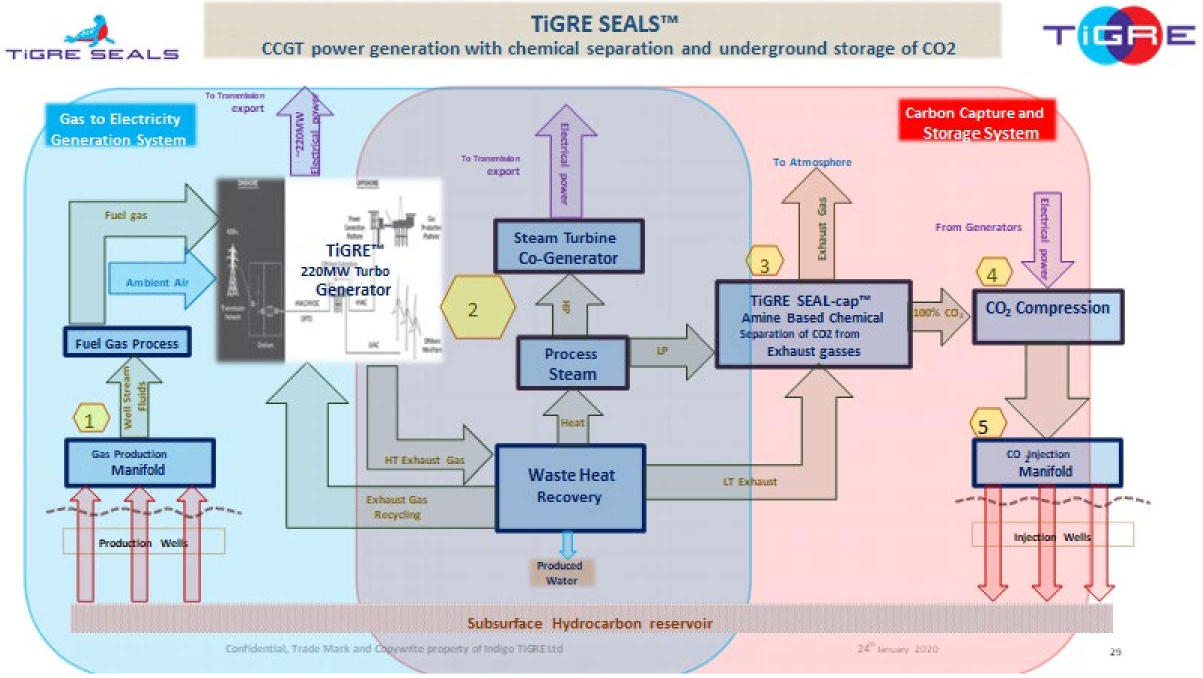

Figure 3: Concept Diagram of Option 1 _ Combined Cycle Gas Turbine Turbogenerator with post combustion CO2 chemical absorption using Amine, CO2 liquification, pumping and storage.

The study undertaken for Milestone 1[1] of the feasibility study identified several significant limitations to operating a chemical absorption process in an offshore environment, mainly due to weight and size limitations, in addition to the logistical challenges of solvent handling and sludge removal.

The HYSYS modelling undertaken during Milestone 2 of the feasibility study has confirmed that the requirements of the absorber columns would present a significant layout challenge for an offshore platform. Significant amounts of Amine chemical makeup would also be required which is not ideal for offshore logistics.

The feasibility study has confirmed through its HYSYS modelling and supporting economic analysis that option 1 is unlikely to be viable in an offshore environment, and the remainder of the BOD therefore focuses on the more technically and economically viable options to take forward: Option 2 and Option 3. See accompanying report entitled TiGRE Technologies Limited CS362 Feasibility Study Report and Recommendations (March 16th, 2020) for further information on the economic modelling.

Option 1 PFDs are included in the Appendix 1 for reference.

1.2.2 Option 2: Combined Cycle CO2 with CO2 enrichment processes and post combustion cryogenic capture of CO2 in solid phase for liquification, pumping and storage.

Concept Description

The TiGRE™ SEALS Post combustion cryogenic CO2 separation concept Figure 4 uses the TiGRE™ CCGT design configured for maximum CO2 concentrations. The CO2 separation is achieved by cryogenic cooling of the exhaust gas stream to enable separation of CO2 in solid phase, followed by reheating to liquid phase at high pressure for reservoir storage through CO2 injection wells. As with the chemical separation process proposed above, this concept largely relies on conventional available technology, with the sole exception of the solid CO2 separator.

Process

- Natural Gas production system using existing wells and producing reservoir. Natural gas can be produced down to 1bar pressures at the production well head and compressed to pressures >60bar for injection into the gas turbine and reheat after burners.
- The primary electrical energy generation plant consists of the basic concept outlined in the concept description (as per section1.1.1 above) defining the TiGRE™ CCGT system. The quantity of exhaust gas reheat energy is maximised to full oxygen depletion and to achieve maximum CO2 concentrations, and there is maximum recycling of the exhaust gases to achieve the same purpose. The objective is to reach the maximum achievable overall saturation of CO2 of above 16.5% by mass, thereby achieving the lowest possible exhaust gas mass flow rate with the highest concentration of CO2.
- The CO2 separation process requires significant dehydration, chilling and refrigeration of the exhaust gas to achieve a target temperature of -120C. Under this condition and partial pressures of CO2, CO2 will achieve greater than 97% freeze out, for mechanical separation, reheat to liquid phase and re-pressurising to around 60bar for storage.

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[1] Offshore CCUS Technology Landscape Assessment

- Liquid CO2 is received from the separation process and storage can be achieved by high-efficiency pumping.
- CO2 is discharged into the same subsurface reservoir which is producing the fuel gas in dense phase which provides the necessary gravity head to permit CO2 injection. CO2 largely remains in dense phase and has the effect of increasing reservoir pressure of time which assists natural gas production through re-pressurisation of the reservoir.
- The subsequent pages show the process design for the TiGRE™ SEALS post combustion cryogenic separation design.

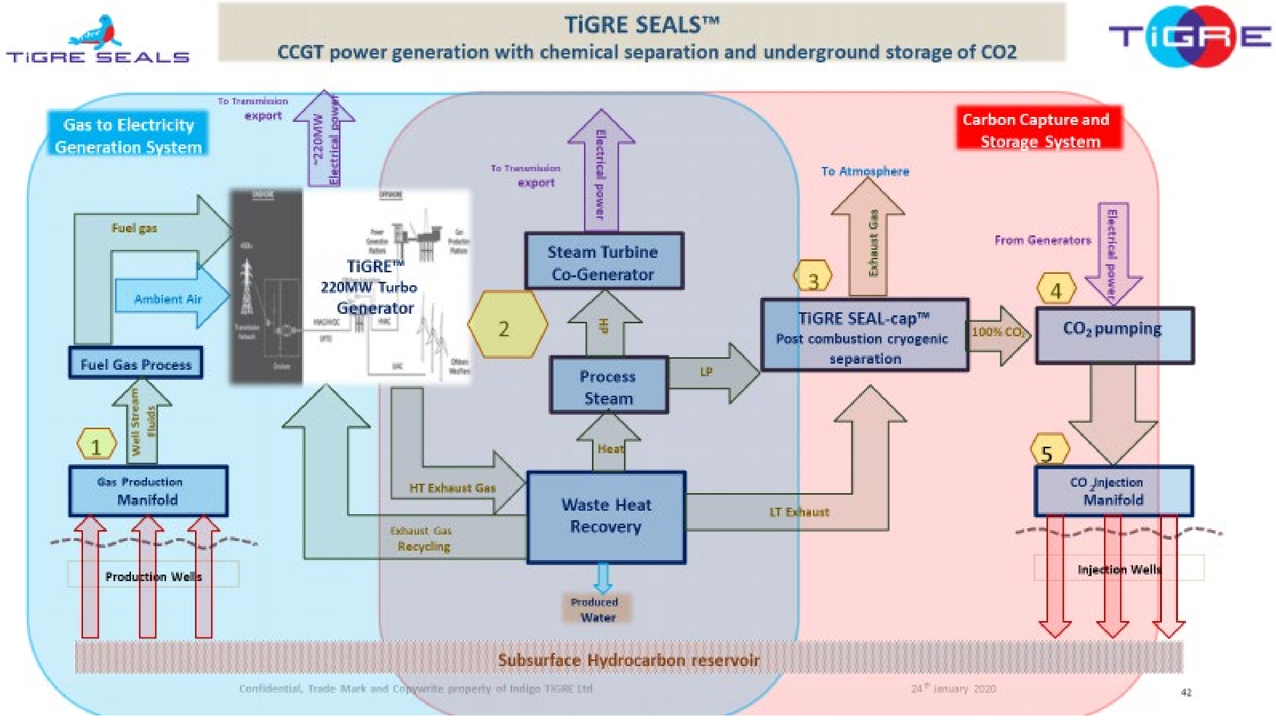

Figure 4: Concept Diagram of Option 2 _Combined Cycle CO2 with CO2 enrichment processes and post combustion cryogenic capture of CO2 in solid phase for liquification, pumping and storage.

1.2.3 Option 3: Oxyfuel direct combustion and expansion through a gas turbine with H2O as supplementary working fluid to capture and store liquid CO2.

Concept Description

The TiGRE™ SEALS Oxyfuel direct combustion concept Figure 5 uses cryogenic air separation to produce high purity oxygen for combustion with natural gas and steam as a combustion temperature regulator and working fluid. The high-pressure high temperature exhaust gases are expanded through a turbo-generator to produce electrical power for export through a transmission system. A heat exchanger system extracts heat and condenses the low-pressure high temperature exhaust gases to allow water CO2 separation and heat recovery to preheat water to low temperature steam prior to recycling through the oxyfuel combustor. Produced CO2 is compressed to dense phase prior to injection by pumping into reworked natural gas production wells for the purpose of CO2 injection and storage.

Process

- Natural Gas production system using existing wells and producing reservoir. Natural gas can be produced down to 1bar pressures at the production well head and compressed to pressures >30bar for injection feed to the Oxyfuel Combustor.
- Cryogenic air separation system produces oxygen through a fractionation process. Nitrogen, Argon and other trace gases are released by to atmosphere after recovering cold heat for the process.
- An oxyfuel combustion process uses oxygen and natural gas as a combustion heat source mixed with low temperature high pressure steam as a temperature moderator and working fluid density increaser. Exhaust conditions are to be maintained below allowable Turbine inlet temperatures and fluid density & flow rates.
- A multi-stage turbine expands the high-pressure hot exhaust gas to low pressure producing work to drive an asynchronous, grid connected electrical generator.
- A system of heat exchangers designed to extract heat from the exhaust gases to be used to preheat the returned condensed steam after CO2 has been separated from the steam/CO2 exhaust gas mix. Returned water is pumped to high pressure prior to preheating to vapour phase for reuse with the oxyfuel combustion process. Seawater cooling is used as the main cooling source for the exhaust gas condensed water prior to CO2/water prior to the separation process.
- CO2 separation from water is managed through a first stage two phase separator followed by a second stage degasser process to extract remaining low concentrations of CO2 from the produced water prior to circulation back to the pumping and preheat cycle within the heat recuperation process. Excess produce water with less than 0.05% CO2 concentration is removed and discharged to maintain the design water mass flow in the recycled system.
- Separated CO2 of concentrations of 92% from the process in (6) is compressed through a multi-stage process and cooled with seawater to drop into liquid phase. Compressors are electrically driven using power generated by the turbo-generators, and residual produced water is separated at each of the compression stages.
- CO2 is discharged into the same subsurface reservoir which is producing the fuel gas in dense phase which provides the necessary gravity head to permit CO2 injection. CO2 largely remains in dense phase and has the effect of increasing reservoir pressure of time which assists natural gas production through re-pressurisation of the reservoir.

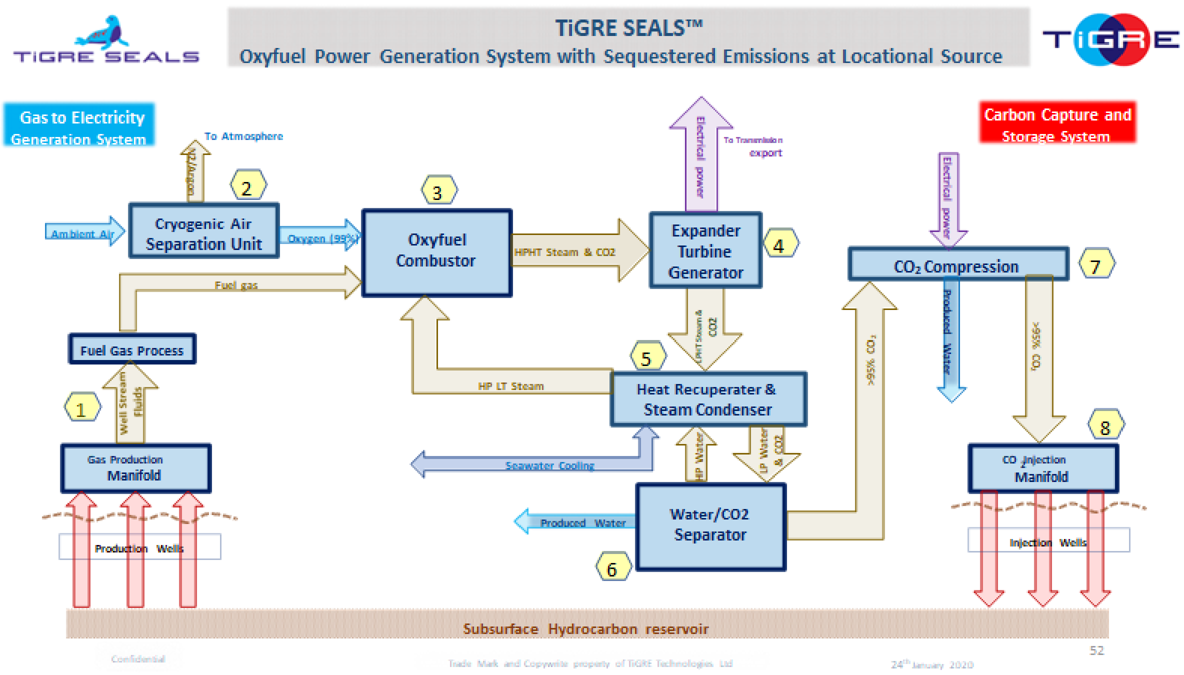

Figure 5: Concept Diagram of Option 3 _Oxyfuel direct combustion and expansion through a gas turbine with H2O as supplementary working fluid to capture and store liquid CO2.

1.2.4 Subsurface Model for CO2 Storage

As part of the TiGRE™ SEALS feasibility study Schlumberger were engaged to develop and build a model to characterise and analyse reservoir behaviour under TiGRE™ and CCUS conditions. Model output included the following:

- Preliminary review on impact of permanently storing the captured CO2 into a generic gas production reservoir.
- Determine dispersion of injected CO2 for long term CO2 storage to highlight potential hydrodynamic integration with existing reservoir production.
- Confirm CITHP & FTHP well head pressured profile for sizing topside CO2 compression requirements.
- Identify how injection of CO2 into the reservoir affects operating conditions of TiGRE™ SEALS.

To achieve these objectives a simplified layered reservoir model was built that would function as the base TiGRE™ SEALS reservoir model. Publicly available data was used to derive a generic target set of SNS reservoir characteristics to be used such as reservoir depth, porosity and permeability layering. These data points were used to construct a realistic base case scenario.

A separate report[2] has been issued to report on the inputs and results of the reservoir modelling. The key BOD parameters used to construct the model are included below in this document.

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[2] Feasibility Study _Reservoir Behavioural Characterisation & Analysis under TiGRE™ and CCUS Conditions_17th Dec 2019, Schlumberger

1.3 Change Control

The data in this document will be updated as required as the project moves from feasibility through further study work, FEED and Design phases.

1.4 Technical Design Methodology / Assumptions

1.4.1 Methodology

The Feasibility Study has been undertaken using the following methodology:

- Technical feasibility assessments of concept designs under investigation have been evaluated by constructing complete steady state process simulations for each concept with sufficient levels of detail to provide confidence that simulations are correctly representative of the design concepts.

- Aspen Tech's AspenONE product portfolio was used as the primary tool to construct process simulations for each of the concepts. Specific AspenONE applications that have been used include:
  - HYSYS V11
  - Aspen Plate Exchanger
  - Aspen Shell & Tube Exchanger
  - Aspen Shell & Tube Mechanical
  - Acid Gas Cleaning
  - Activated Exchanger Design & Ratings
  - Aspen Capital Cost Estimator
  - Aspen in Plant Capital Cost Estimator

- Specific stream components were selected for the concepts under consideration as appropriate from two selected fluid packages from those available within the HYSYS environment as follows:
  - HYSYS Peng-Robinson fluid package was used for all processes and components for heat and mass balance, fluid dynamics and mechanics that did not require rate-based solutions.
  - Acid Gas – Chemical Solvents fluid package was used for simulations involving solvent based CO2 chemical reactions which are rate based. This fluid package was used for chemical absorption/regeneration simulation and column design.

- Empirical data for plant and equipment component performance has been provided from OEM's and assumptions (including those from a literature review) were used to inform the simulation modelling.

- Equipment sizing and specification data used by the simulation models were mostly produced by the generic tools in HYSYS. Key, specific equipment items, for example heat exchangers and separation vessels, which are critical or bespoke to the design concept have been engineered with an optimised solution. Other specialist equipment, such as gas turbines and compressors have been modelled to replicate the respective published OEM's performance specifications to ensure simulations are reflective of available equipment for these key components.

- The boundary encompassing the process design simulations undertaken by HYSYS modelling is defined to be from the natural gas production wellhead to the CO2 storage injection wellhead. All other processes (specifically sub-surface) are considered in the separate parallel report as undertaken by Schlumberger as part of this feasibility project. The single two interface points between the two sets of modelling are the process stream conditions for the production natural gas and the produced CO2 for storage. Each of the CCUS process under consideration by this project have differing operating conditions relating to these two product streams, and the two modelling processes have looked to ensure consistency and alignment of the modelling simulations to ensure combining of the two provides valid results.
  - All process design, simulations and subsequent results used and referred to in this report are based on steady state simulations. Specific scenarios have been modelled to provide dynamic characterisation to evaluate discrete start up and ramp up conditions for some of the processes which may require temporal analysis.
  - At this feasibility stage of development, a stochastic approach to all modelling has been utilised. A probabilistic approach is expected to be deployed at the next stage of the selected concept(s) development through FEED and is therefore outside the scope of this feasibility study.

- A simple Geological model “layer cake” was adopted For the Reservoir simulation modelling with the following constraints in the model recognised:
  - No Aquifer drive effects were considered.
  - No CO2 mixing/reaction with bound water of formation minerals were considered.
  - No Modelling of impact of the Joule-Thomson Effect (Isothermic reservoir and well modelling has been undertaken) was undertaken.

- As a feasibility the design at this stage is limited. The following areas that have been identified through the feasibility study as requiring to be addressed during the FEED stage:
  - Modelling of dynamic operational conditions (start-up/shutdown etc).
  - Pressure relief or blowdown facilities.
  - Drains facilities.
  - Use of available gas Export pipelines as a fuel gas storage buffer including fuel gas dehydration requirements.
  - Electrical Connection options at selected Offshore Wind Farm Substation.
  - Review or redundancy/standby requirements for key equipment items.
  - Firefighting Requirements.
  - Utilities requirements.
  - Controls and Telecoms’ Requirements.

1.4.2 Assumptions /Data Sources

The design and analytical work undertaken in support of evaluating the various design concepts contemplated in this report utilised several assumptions and empirical input data. Wherever possible this data (assumed or empirical) has been utilised consistently across the design and analysis of the concepts in order to ensure that valid comparisons of the respective results from the concepts can be undertaken. The key generic assumptions and empirical data sources used include the following:

- Composition of the fuel gas under consideration.
- Composition of feed Air.
- Gas Turbine and Turbo-generator performance as specified by propriety OEM data.
- Gas compressor performance as specified by propriety OEM data.

- Cryogenic air separation equipment for oxygen production as provided by propriety OEM data.
- Oxyfuel combustion equipment specification as supplied by propriety OEM data.
- Actual data from generic Field Well Log for the reservoir modelling.

2 COMPOSITIONAL DATA

2.1 Reservoir Properties

Generic Reservoir Model Description[3]

General Lithology Description

The Rotliegendes formation being a common formation encountered in the Southern North Sea was used as a typical SNS geology. A representative reference case of a typical SNS Rotliengendes reservoir was used to inform identification of the initial basic model input parameters which were adjusted where necessary to provide a functional model that could be used to simulate reservoir performance within the TiGRE™ SEALS closed loop concept.

Generic Reservoir Layered Heterogeneity Description

The geological structure assumed within the reservoir model consists of multiple layers (a “layer cake”) derived from the generic Field Well Log with each layer being modelled as a simple homogeneous layer. This is recognized as an acceptable simplification of an actual reservoir which is likely to have more heterogeneous characteristics within the layers.

The reservoir modelled is based on a gentle dip structure.

Parameter	Units	Base Case	Sensitivity analysis
Sedimentary Rock Type/Make up	N/A	Rotliengendes	
GIIP of undepleted reservoir	BCF	430	300 & 600
Depletion level from Initial conditions relative to GIIP	%	60	50 & 70
Porosity	N/A	0.4	
Permeability	Darcy (mD)	17	8.5 & 170
Max Reservoir Pressure	Psig	4500 (Hydrostatic +10% overpressure)	
Reservoir pressure @ Depletion level	psig	1,700	2138 & 1320

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[3] Source: Feasibility Study _Reservoir Behavioural Characterisation & Analysis under TiGRE™ and CCUS Conditions_17th Dec 2019, Schlumberger

Temperature	Deg F	220	
Reservoir Depth	m	2,400	
Reservoir Thickness	m	35	
Reservoir Length	m	10,000	
Reservoir Width	m	3,000	
Reservoir Bulk Volume	Ft3	69,637	
Injection pressure of CO2 at Injection wellhead	psig	800	
Injection temperature of CO2 at Injection wellhead	Deg F	40	
Co2 Injection Rate @ Wellhead	Kg/sec	10	40
Level of CO2 breakthrough in production riser where Producer shut in.	%	30	
Reservoir pressure whereby CO2 injection is shut in.	psig	4500 (Hydrostatic +10%)	
Co2 injection Cycle		18hrs on/off for Autumn, Winter, Spring months. 18hrs on/150hrs off for Summer months	
Reservoir production rate	MMSCF/D	15 (when CO2 Injection occurs)	15 (continual production)
CO2 breakthrough in Producer indicators reported.	%	5	20

Table 1: Reservoir Model Operating Scenarios & Sensitivities

2.2 Production Gas Hydrocarbon Properties

Property	**Mole %**		
	Gas	**Conde**	**Mix**
Methane	91	31	91
Nitrogen	3.4	0.5	3.5
Ethane	3	5	3
Co2	0.8	0.7	0.8
Helium	0.051	0.00	0.050
Hydrogen	0.003	0.000	0.000

Argon/Oxygen	0.009	0.000	0.010
Propane	0.696	3.220	0.700
Iso Butane	0.130	1.310	0.130
n-butane	0.164	2.200	0.160
Neo-pentane	0.006	0.000	0.010
Iso pentane	0.052	1.480	0.050
N pentane	0.052	1.880	0.050
Cyclopentane	0.006	0.000	0.010
Hexanes	0.058	10.740	0.060
Methylcyclopentane	0.005	0.000	0.000
Benzene	0.035	0.000	0.040
Cyclohexane	0.017	0.000	0.020
Heptanes	0.024	12.260	0.030
Methylcyclohexane	0.112	0.000	0.010
Toluene	0.008	0.000	0.010
Octanes	0.008	6.370	0.010
Nonanes	0.005	8.060	0.010
Dectanes	0.000	5.950	0.000
C_11	0.000	4.060	0.000
C_12	0.000	4.810	0.000
Total	100	100	100

Table 2: Production Gas Hydrocarbon Properties

3 INPUT/OUTPUT DATA

3.1 Project Size/Output Capacity

Concept Option	GT Model Based on	Gross Electrical power Generated (MW)	Net Output power to Grid (MW)
Option 1: CCGT with post combustion Chemical Absorption (Amine) CO2 Capture	Open Cycle Gas Turbine	218	193
Option 2: CCGT with CO2 Enrichment processes and post combustion cryogenic capture of CO2	Open Cycle Gas Turbine	250	203
Option 3: Oxy fuel Combustion and expansion through a gas turbine	Oxy Fuel combustor Gas Turbine Generator	266	196.9

Table 3: Project Size/Output Capacity

3.2 Environmental Conditions

Condition	Units	Value
Air Temperature	Deg C	-8 to 27 (100 year min, max) (Average 15)
Seawater Temperature (sea surface)	Deg C	0 to 23 (100year min. max) (12 Average)
Water Depth (relative to LAT)	m	36

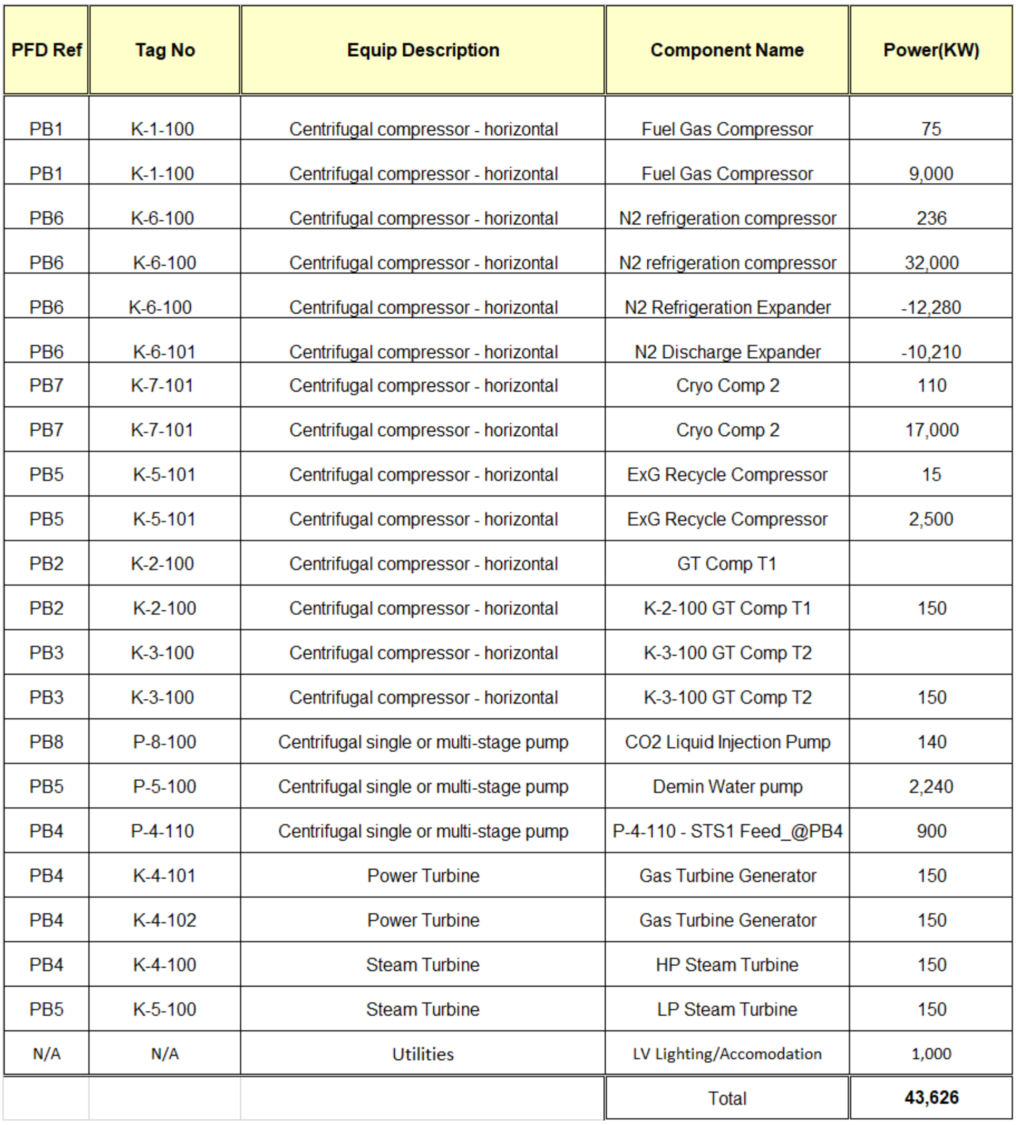
Table 4: Environmental Conditions

4 OPTION 2: COMBINED CYCLE COGENERATION WITH ENRICHMENT PROCESSES AND POST-COMBUSTION CRYOGENIC CAPTURE OF CO2 IS SOLID PHASE FOR LIQUIFICATION, PUMPING AND STORAGE.

4.1 Process Flow Diagrams

Reference Appendix 2 for the Process Flow Diagrams for Option 2

4.2 Equipment Load List (Option 2)



PFD Ref	Tag No	Equip Description	Component Name	Power(KW)
PB1	K-1-100	Centrifugal compressor - horizontal	Fuel Gas Compressor	75
PB1	K-1-100	Centrifugal compressor - horizontal	Fuel Gas Compressor	9,000
PB6	K-6-100	Centrifugal compressor - horizontal	N2 refrigeration compressor	236
PB6	K-6-100	Centrifugal compressor - horizontal	N2 refrigeration compressor	32,000
PB6	K-6-100	Centrifugal compressor - horizontal	N2 Refrigeration Expander	-12,280
PB6	K-6-101	Centrifugal compressor - horizontal	N2 Discharge Expander	-10,210
PB7	K-7-101	Centrifugal compressor - horizontal	Cryo Comp 2	110
PB7	K-7-101	Centrifugal compressor - horizontal	Cryo Comp 2	17,000
PB5	K-5-101	Centrifugal compressor - horizontal	ExG Recycle Compressor	15
PB5	K-5-101	Centrifugal compressor - horizontal	ExG Recycle Compressor	2,500
PB2	K-2-100	Centrifugal compressor - horizontal	GT Comp T1	
PB2	K-2-100	Centrifugal compressor - horizontal	K-2-100 GT Comp T1	150
PB3	K-3-100	Centrifugal compressor - horizontal	K-3-100 GT Comp T2	
PB3	K-3-100	Centrifugal compressor - horizontal	K-3-100 GT Comp T2	150
PB8	P-8-100	Centrifugal single or multi-stage pump	CO2 Liquid Injection Pump	140
PB5	P-5-100	Centrifugal single or multi-stage pump	Demin Water pump	2,240
PB4	P-4-110	Centrifugal single or multi-stage pump	P-4-110 - STS1 Feed_@PB4	900
PB4	K-4-101	Power Turbine	Gas Turbine Generator	150
PB4	K-4-102	Power Turbine	Gas Turbine Generator	150
PB4	K-4-100	Steam Turbine	HP Steam Turbine	150
PB5	K-5-100	Steam Turbine	LP Steam Turbine	150
N/A	N/A	Utilities	LV Lighting/Accomodation	1,000
			Total	**43,626**

Table 5: Load List_Option 2

4.3 Equipment Data (Option 2)

4.3.1 Compressors (Option 2)

PFD Drawing Reference	Tag No	Description	Actual gas flow rate Inlet (M3/H)	Casing material	Compressor speed (RPM)	Design gauge pressure Inlet (KPAG)	Design gauge pressure Outlet (KPGA)	Design temperature Inlet (Deg C)	Driver power (KW)	Driver type	Item type	Number of impellers	Total weight (KG)
PB1	K-1-100	Fuel Gas Compressor	46,413	A285C	8,448	0.0	3,929	15	9,000	MOTOR	CENTRIF	9	68,800
PB6	K-6-100	N2 refrigeration compressor	28,280	A285C	8,924	871.7	14,494	20	31,968	MOTOR	CENTRIF	10	110,900
PB7	K-7-101	Cryo Compressor 2	136,084	A285C	4,889	237.7	899	20	16,895	MOTOR	CENTRIF	3	111,300
PB5	K-5-101	Ext Gas Recycle Compressor	396,515	A285C	2,149	-12.3	9	15	2,500	MOTOR	CENTRIF	1	172,600
PB6	K-6-101	N2 Discharge Expander											
PB7	K-7-100	Cryo Compressor 1											

Table 6: Equipment Data (Option 2)_Compressors

4.3.2 Heat Exchangers (Option 2)

					Shell							Tube					
PFD REF	Tag No	Description	Heat transfer area (M2)	TEMA type	Number of shells	Area per shell (m2)	Shell design gauge pressure (KPAG)	Shell design temperature (DegC)	Shell diameter (mm)	Shell length (m)	Shell material	Tube design gauge pressure (KPAG)	Tube design temperature (DEGC)	Tube length extended (m)	Tube material	Tube outside diameter (mm)	Total weight (KG)
PB8	E8-104	LCO -Q recovery	48	BEM			1,044	-95	350	6	A285C	1,047	-55.0	6	A 214	25	1,600
PB8	E-8-103	E-8-103 N2 -Q Recovery		BEM	2	840	1,044	-130	1425	6	A285C	1,045	-122.0	6	A 214	25	36,000
PB8	E-8-102	ExG / N2 HE	173	BEM			663	-101	650	6	A285C	1,046	-70.4	6	A 214	25	4,500
PB8	E-8-101	ExG/N2 HE	1155	BEM			671	-57	1700	6	A285C	1,057	22.0	6	A 214	25	23,700
PB8	E-8-100	ExG/CO2 HE	40	BEM			6,244	-53	350	6	A285C	4,129	22.0	6	A 214	25	2,100
PB1	E-1-100	Fuel Gas Cooler	128	BEM			4,274	393	575	6	A285C	2,815	392.7	6	A 214	25	5,400
PB6	E-6-102	N2/N2 HE	484	BEM			10,114	-100	1075	6	A285C	15,221	22.0	6	A 214	25	36,900
PB6	E-6-101	N2/N2 HE	364	BEM			15,222	125	950	6	A285C	10,114	125.0	6	A 214	25	40,000
PB6	E-6-100	H2O/N2 HE	771	BEM			20,955	221	1375	6	A285C	31,483	221.4	6	A 214	25	148,900
PB7	E-7-104	ExG HE	447	BEM			418	166	1050	6	A285C	245	166.0	6	A 214	25	10,100
PB7	E-7-102	ExG SW precooler	351	BEM			1,059	139	925	6	A285C	672	138.5	6	A 214	25	8,300
PB7	E-7-101	Cryo HR	594	BEM			20,954	207	1200	6	A285C	31,482	206.6	6	A 214	25	110,700
PB7	E-7-100	ExG precooler	154	BEM			129	125	625	6	A285C	244	125.0	6	A 214	25	4,100
PB5	E-5-103	ExG Recycle cooler	77	BEM			244	125	450	6	A285C	244	125.0	6	A 214	25	2,300
PB5	E-5-102	ExG SW cooler		BEM	2	989	129	245	1550	6	A285C	244	245.0	6	A 214	25	39,600
PB5	E-5-100	Seawater Condensor No2		BEM	3	1118	129	128	1675	6	A285C	244	128.2	6	A 214	25	65,700
PB4	E-4-101	Steam Condensor	853	BEM			242	130	1425	6	A285C	414	129.6	6	A 214	25	17,500
PB4	E-4-100	Main Steam Generator Heat Exchanger															
PB4	E-4-102	Main Steam Evaporator															
PB5	E-5-101	Evaporator No2															
PB7	E-7-103	Cry Comp Discharge Cooler															

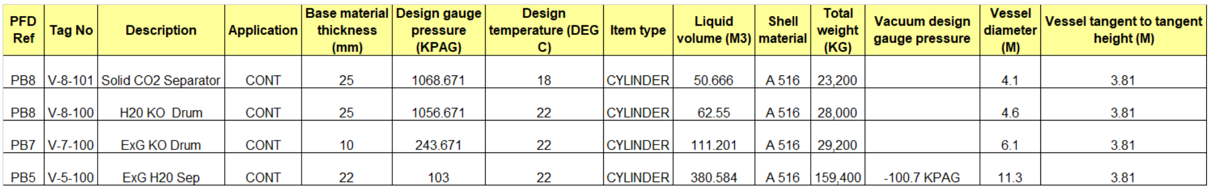
Table 7: Equipment Data (Option 2)_Heat Exchangers

4.3.3 Pumps (Option 2)

PFD Ref	Tag No	Description	Casing material	Design gauge pressure (KPAG)	Design temperature (DEG C)	Driver power (KW)	Driver type	Fluid head	Item type	Liquid flow rate L/S	Speed	Total weight
PB8	P-8-100	Co2 Well Injection Pump	CS	6,244	18	140.001	MOTOR	428.903 M	CENTRIF	21.644	3000.000 RPM	2500 KG
PB5	P-5-100	H2O	CS	31,483	22	2240.001	MOTOR	3017.476 M	CENTRIF	59.618	3000.000 RPM	160400 KG
PB4	P-4-110	Condensed water Steam Feed Pump	CS	33,499	128	900	MOTOR	3421.693 M	CENTRIF	23.108	3000.000 RPM	156800 KG

Table 8: Equipment Data (Option 2)_Pumps

4.3.4 Vessels (Option 2)



PFD Ref	Tag No	Description	Application	Base material thickness (mm)	Design gauge pressure (KPAG)	Design temperature (DEG C)	Item type	Liquid volume (M3)	Shell material	Total weight (KG)	Vacuum design gauge pressure	Vessel diameter (M)	Vessel tangent to tangent height (M)
PB8	V-8-101	Solid CO2 Separator	CONT	25	1068.671	18	CYLINDER	50.666	A 516	23,200		4.1	3.81
PB8	V-8-100	H20 KO Drum	CONT	25	1056.671	22	CYLINDER	62.55	A 516	28,000		4.6	3.81
PB7	V-7-100	ExG KO Drum	CONT	10	243.671	22	CYLINDER	111.201	A 516	29,200		6.1	3.81
PB5	V-5-100	ExG H20 Sep	CONT	22	103	22	CYLINDER	380.584	A 516	159,400	-100.7 KPAG	11.3	3.81

Table 9: Equipment Data (Option 2)_Vessels

4.3.5 Power Turbines (Option 2)

For the purposes of the HYSYS process modelling a generic OCGT was used for the four gas turbines outlined in Table 10 . Standard OCGT weight and dimensions have been applied in the weight register and for the indicative layouts.

Gas Turbine No	PFD Equipment Tag Nos	Equipment Tag Description	Output Power (Kw)
GT-1	K-2-100	Air Compressor	
	GBR-2-100	Combustor T1	
	K-2-101	Primary Power Turbine	70,000 No electrical output power derived (All power used to drive K-2-100)
GT-2	K-3-100	Air Compressor	
	GBR-3-100	Combustor T2	
	K-3-101	Primary Power Turbine	70,000 No electrical output power derived (All power used to drive K-2-100)
Gen 1	GBR-4-100	Reheat Burner	
	K-4-101	Power Turbine	86,000
Gen 2	GBR-4-100	Reheat Burner	
	K-4-102	Power Turbine	86,000

Table 10: Equipment Data (Option 2)_Gas Turbine Arrangement

Steam Turbine No	Equipment Tag Nos	Equipment Tag Description	Output Power (Kw)
Gen 3	K-4-100	HP Steam Turbine	22,3200
Gen 4	K-5-100	LP Steam Turbine	55,700

Table 11: Equipment Data (OPTION 2)_Steam Turbine Arrangement

5 OPTION 3_ OXYFUEL COMBUSTION & EXPANSION THROUGH A POWER TURBINE WITH H2O AS SUPPLEMENTAL WORKING FLUID + CAPTURE AND STORAGE OF CO2

5.1 Process Flow Diagrams (Option 3)

Appendix 3 contains the Process flow Diagrams for Option 3.

5.2 Equipment Load List (Option 3)

Tag No	**Equip Description**	**Component Name**	**Power(KW)**
K-2-100	Centrifugal compressor	Fuel gas compressor	75
K-2-100	Centrifugal compressor	fuel gas compress	8,000
K-3-102	Centrifugal compressor	3rd Stg CO2 comp_	60
K-3-102	Centrifugal compressor	3rd Stg CO2 comp_	5,000
K-3-101	Centrifugal compressor	2nd Stg CO2 Comp_	30
K-3-101	Centrifugal compressor	2nd Stg CO2 Comp_	2,500
K-3-100	Centrifugal compressor	1st Stage CO2 Comp	2,633
K-1-101	Centrifugal compressor	ASU MAC Stg2	90
K-1-101	Centrifugal compressor	ASU MAC Stg2	16,000
K-1-100	Centrifugal compressor	ASU MAC Stg1	75
K-1-100	Centrifugal compressor	ASU MAC Stg1	13,000
P-2-101	Centrifugal Pump	Produced Water Recycle Pump	1,400
P-2-100	Centrifugal Pump	LOX booster pump_	212
P-4-103	Centrifugal Pump	Cooling Water Booster Pump	11
P-4-102	Centrifugal Pump	Cooling Water Booster Pump	15
P-4-101	Centrifugal Pump	Cooling Water Booster Pump	19
P-4-100	Centrifugal Pump	Submersible SW lift Pump	2,000
LR-CD_@COL-1	Centrifugal Pump	LR-CD_@COL-1-100 ASU Fra	80
LC-CD_@COL-1	Centrifugal Pump	LC-CD_@COL-1-100 ASU Fra	125
GT-1-100	Gas Turbine	Primary (Train 1)	130
GT-1-101	Gas Turbine	Secondary (Train 1)	130
GT-2-100	Gas Turbine	Primary (Train 2)	130
GT-2-101	Gas Turbine	Secondary (Train 2)	130
LV Utilities/Lighting/Living Quarters			1,000
		TOTAL	52,845

Table 12: Option 3 Oxy Fuel Power Load List

5.3 Water Requirements (Option 3)

Water Type	Duty	Quantities (flowrate) (L/S)	Source	Storage Requirements (L)	Discharge Conditions
Seawater	Cooling via heat exchangers for ➢ ASU demin cooling water ➢ CO2 compressor demin cooling water ➢ Oxyfuel combustor demin cooling water	1626	Sea	N/A	43.92DegC overboard.
Reflected in PFDs as 3 separate closed loop cooling water systems. **See Note 1 below.**	Cooling for ➢ ASU ➢ CO2 Comp ➢ Oxyfuel combustor	1562	Sea	N/A see note above.	Discharged to sea (Conditions to be established).
Produced Water	➢ Required for steam feed into combustion chamber.	175	Output from combustion process following CO2 water separation. [Further treatment method to be determined. **See Note 2 below**]	V-2-100	Unused PW discharged overboard into sea at 31Deg C
Potable water	Personnel domestic use	0.02	Either/or ➢ Water maker on board ➢ Bunkering from supply vessel	20000	Used water discharged overboard.

Table 13: Option 3_OxyFuel Combustion_ Water Requirements

Note 1 (Table 13**):** The PFDs for option 3 show 3 separate closed loop cooling water system for cooling the exhaust gases, the CO2 compressor inter stage cooling and ASU cooling processes. The closed loop water systems each being cooled by seawater via heat exchangers. It has now been determined that these closed loop cooling water systems would most likely be replaced by direct cooling from the service water (seawater) system which is an open loop system and therefore does not require the need for storage tanks/top up tanks you would require in a closed loop system.

Note 2 (Table 13**):** The Produced Water recycled in the form of steam to the Combustion chamber of the oxyfuel combustion chamber will require to be demineralised. The process for demineralising the produce water is not included at feasibility phase for simplicity but will be reviewed at the FEED study phase.

5.4 Equipment Data (Option 3)

This section contains the main equipment list and key specifications[4] used for the design at feasibility phase.

5.4.1 Compressors (Option 3)

PFD Ref	Tag No	Description	Item type	Actual gas flow rate Inlet (M3/H)	Casing material	Compressor speed (RPM)	Design pressure Inlet (KPAG)	Design gauge pressure Outlet	Design Temperature Inlet (DEG C)	Design Temperature Outlet (DEG C)	Driver power (KW)	Driver type	Number of impellers	Total weight (KG)
PB2	K-2-100	Fuel gas compressor	CENTRIF	42,253	A285C	8,057	0	5,899	15	399	7,983	MOTOR	9	76,500
PB3	K-3-102	3rd Stg CO2 comp_	CENTRIF	5,823	A285C	20,167	1378.8	6,400	23	167	5,000	MOTOR	3	21,200
PB3	K-3-101	2nd Stg CO2 Comp_	CENTRIF	12,699	A285C	14,109	271.204	1,389	28	150	2,500	MOTOR	3	17,300
PB3	K-3-100	1st Stg CO2 Comp_	CENTRIF		A285C		93	374	31	163	2,633	MOTOR		
PB1	K-1-101	ASU MAC Stg2	CENTRIF	194,570	A285C	4,212	128.671	519	28	143	16,000	MOTOR	3	137,400
PB1	K-1-100	ASU MAC Stg1	CENTRIF	428,413	A285C	2,708	0	139	15	109	13,000	MOTOR	3	271,400

Table 14: Option 3 Equipment data_Compressors

5.4.2 Heat Exchangers (Option 3)

PFD Reference	Tag No	Description	TEMA type	Shell									Tube							Total weight (kg)
				Area per shell (M2)	Fluid	Heat transfer area (M2)	Number of shells	Shell design gauge pressure (KPAG)	Shell design temperature (DEG C)	Shell diameter (MM)	Shell length (m)	Shell material	Fluid	Tube design gauge pressure (KPA)	Tube design temperature (DEG C)	Tube length extended (m)	Tube material	Tube outside diameter (mm)	Tube port diameter	
PB2	E-2-101	Exhaust Gas HE	CEN		Water	4,386		499	135	3,000	7.5	A 516	Combustion Exhaust Gas	199	100	7.5	A 214	19.1		97,400
PB2-2	E-2-2-100	Exghaust Gas/PW	BEM	1,057	Combustion Exhaust Gas		3	4,129	625	1,625	6	SS304	Produced Water	6,244	625	6.0	304W	25.0		348,300
PB2-1	E-2-1-100	Exhaust Gas/PW	BEM	1,057	Combustion Exhaust Gas		3	4,129	625	1,625	6	SS304	Produced Water	6,244	625	6.0	304W	25.0		348,300
PB3	E-3-101	1st Stage CO2 Compressor Discharge Cooler	BEM		Water	67		556	125	450	6	A285C	CO2	442	193	6.0	A 214	25.0		2,200
PB3	E-3-100	3rd Stage CO2 Compressor Discharge cooler	BEM		Water	697		4,463	125	1,300	6	A285C	CO2	6,745	197	6.0	A 214	25.0		27,900
PB3	E-100	2nd Stage CO2 Compressor Discharge cooler	BEM		Water	74		1,559	180	450	6	A285C	CO2	1,005	180	6.0	A 214	25.0		2,400
PB2	E-2-100	LOX feed preheate	BEM		Water	208		4,135	22	725	6	A285C	O2	6,254	22	6.0	A 214	25.0		8,500
PB1	E-101	ASU Stage 1 air compresor discharge	BEM	1,372	Water		4	565	125	1,825	6	A285C	Air	343	139	6.0	A 214	25.0		106,800
PB1	E-100	ASU Argon/Air	BEM	1,359	N2/ Argon		16	419	125	1,825	6	A285C	Air	679	125	6.0	A 214	25.0		428,800
PB1	E-1-100	ASU Stage 2 air compresor discharge	BEM	1,128	Water		3	565	125	1,675	6	A285C	Air	689	173	6.0	A 214	25.0		67,500
PB1	COL-1-100	UC-reboiler	BKU			92		472	-209	1,000	4	A285C		758	194	6.0	A 214	25.0	686	3,200
PB4	E-4-102	ASU Demin water/SW	BEM	6,273	Water		3	999	80	739	8	A 516	Water	499	80	8.0	A 214	20.0		260,700
PB4	E-4-101	CO2 Compressor Demin water/SW	BEM	1,359	Water		2	999	80	739	8	A 516	Water	499	80	8.0	A 214	19.1		45,200
PB4	E-4-100	OXY Fuel Combustion Demin water/ SW	BEM	6,323	Water		3	999	125	739	8	A 516	Water	499	80	8.0	A 214	20.0		266,100

Table 15: Option 3 Equipment data_ Heat Exchangers

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[4] HYSYS Project Run Reference:_ TiGRE™ OFGT R52 240220 rh01.hsc

5.4.3 Pumps (Option 3)

PFD Ref	Tag No	Description/Duty	Item type	Casing material	Design pressure (KPAG)	Design temperature (Deg C)	Driver power (kw)	Driver type	Liquid flow rate (L/S)	Speed (rpm)	Total weight (kg)
PB2	P-2-101	Produced Water Recycle	CENTRIF	CS	6,244	125	1400	MOTOR	175	3000	9000
PB4	P-4-103	ASU Cooling water boost	CENTRIF	CS	569	125	11	MOTOR	550	1500	1500
PB4	P-4-102	CO2 Comp Cooling water boost	CENTRIF	CS	569	125	15	MOTOR	439	1500	1200
PB4	P-4-101	Oxy Fuel Combustion Cooling Water Boost	CENTRIF	CS	569	125	18.5	MOTOR	573	1500	1700
PB4	P-4-100	Submersible SW lift	CENTRIF	CS	1,069	22	2000	MOTOR	1626	1500	15400
PB2	P-2-100	LOX booster	CENTRIF	CS	6,254	18	212	MOTOR	29	3000	3200
PB1	LR-CD_@COL-1	Reflux Pump	CENTRIF	CS	244	18	80	MOTOR	45	3000	650
PB1	LC-CD_@COL-1	Reboiler Pump	CENTRIF	CS	619	18	125	MOTOR	178	1500	1300

Table 16: Option 3 Equipment Data_Pumps

Note: The Reflux and Reboiler Pumps are not shown separately in PFD PB1 but are within COL-1-100 package.

5.4.4 Vessels (option 3)

PFD Ref No	Tag No	Description	Vessel Orientation	Base material thickness (MM)	Design gauge pressure (KPAG)	Design temperature (Deg C)	Item type	Liquid volume (m3)	Shell material	Vessel diameter (m)	Vessel tangent to tangent height (m)	Vessel tangent to tangent length (m)	Total weight (kg)
PB1	LR-CD_@COL-1	LR-CD_@COL-1-100 ASU Fra	HORIZONTAL	8	244	18	HORIZ DRUM	18.3	A 516	2.0		5.9	3,500
PB1	LC-CD_@COL-1	LC-CD_@COL-1-100 ASU Fra	HORIZONTAL	12	619	18	HORIZ DRUM	61.2	A 516	2.9		9.3	11,000
PB1	UC trays_@CO	UC trays_@COL-1-100 ASU	VERTICAL	11.3	244	18	TOWER		A 516	5.8	27.0		159,900
PB1	LR column_@C	LR column_@COL-1-100 ASU	VERTICAL	9	244	18	TOWER		A 516	3.4	27.0		63,300
PB1	LC-trays_@CO	LC-trays_@COL-1-100 ASU	VERTICAL	18	625	18	TOWER		A 516	4.9	8.7		52,200
PB2	V-2-100	CO2 / Produced Water Seperator	HORIZONTAL	12	103	125	CYLINDER	76.0	A 516	3.2		9.4	17,600
PB3	V-100	CO2 Compresion 3rd Stage Inlet Separator	VERTICAL	18	1,549	125	CYLINDER	13.6	A 516	2.1	3.8		5,800
PB3		CO2 Compressor 2nd Stage Inlet separator	VERTICAL	8	441	125	CYLINDER	13.6	A 516	2.1	3.8		2,900

Table 17: Option 3 Equipment Data Vessels

5.4.5 Gas Power Turbine (Option 3)

For the purposes of the HYSYS process modelling a standard OCGT has been used to represent the Oxyfuel combustion and power turbine elements. Fuel gas supply pressure requirements and output power are in accordance with market available OCGT product.

The standard OCGT without the air compressor has been used as an approximation to represent the Oxyfuel combustion and power turbine for the weight calculation and dimensions for layouts.

For the purposes of this feasibility study the oxyfuel gas turbines are represented as fout separate gas turbines each driving a separate electrical generator. The oxyfuel gas turbines are represented this way in the PFDs as follows:

Gas Turbine No	Equipment Tag Nos	Equipment Tag Description	Output Power (Kw)
G-1-100 (Train 1)	GBR-2-1-100	Primary Combustor 1	
	K-2-1-100	Primary Power Turbine	68,000
G-1-101 (Train 1)	GBR-2-1-101	Primary Combustor 1	
	K-2-1-101	Primary Power Turbine	65,000
G-2-100 (Train 2)	GBR-2-2-100	Primary Combustor 1	
	K-2-2-100	Primary Power Turbine	68,000
G-2-101 (Train 2)	GBR-2-2-101	Primary Combustor 1	
	K-2-2-101	Primary Power Turbine	65,000

Table 18: Option 3 Gas Turbine Generator Configurations

6 ELECTRICAL SUBSTATION (OPTION 2 & 3)

6.1 Electrical System Design

The Electrical Systems for Option 2 & 3 are similar for the purposes of the feasibility study and therefore the explanation in this section will cover for both. Where there are differences, these will be highlighted.

The similar Single Line Diagrams for both Options are included in Appendix 4 (option 2) and Appendix 5 (Option 3)

Note: At feasibility stage an electrical load study has not been undertaken (this would be undertaken at FEED) to confirm actual number and electrical ratings of the electrical equipment shown on the SLD, relying on inhouse expertise. A full FEED study would also confirm the requirements of the electrical design to comply with the required transmission grid codes issued by the national grid.

6.1.1 Medium Voltage System (11kv)

Electricity is generated via connected synchronous generators operating in parallel generating at 11kv & at 50Hz with a total output of 250MW (289MVA) for option 2 and 266MW (300MVA) for option 3. The generators are protected by circuit breakers located on each unit.

Medium Voltage (MV) Switchboards also supply the direct MV drives of which the main ones are expected to include:

- ASU Air Compressors (Option 3)
- Fuel Gas Compressors
- CO2 Compressors
- CO2 Injection pumps
- Service Water pumps
- Cooling Water Pumps

In addition, the MV switchboards will also supply the Low Voltage (LV) switchboards via two 2MVA, 11kv/415v transformers to step the voltage down to 415v. The MV Switchboards will be located in the MV Switchroom (SWR-MV)

6.1.2 High Voltage System (132kv) OFTO Assets

75MVA Transformers will transform the generation voltage level up to 132kv (HV) which is the minimum operating voltage of the Offshore Transmission System operated by the Offshore Transmission Operator (OFTO).

A 132kv switchboard will contain Gas Insulated Switchgear (GIS), which will be located in a High Voltage (HV) Switchroom (HV_SGM) in addition to the metering required to monitor power export.

The Reactor Room (REA) contains the Power Factor Compensation equipment which is at 132kv and will be part of the OFTO assets.

All Equipment at 132kv would be owned and operated by an OFTO appointed by OFGEM. The 132kv, 1000A export circuit breaker will supply a 132kv cable that will be routed to transmit the power to a downstream OFTO operated Offshore substation whereby the Transmission infrastructure to the onshore substation will be shared with a windfarm.

Other Transmission voltage options are available to be used depending upon proximity of the substation TiGRE™ would connect to. The final transmission voltage can be determined once the connection point is established.

6.1.3 Low Voltage System (415v)

A Low Voltage (LV) switchboard supplies the LV loads which include:

- Lighting
- Utilities such as compressed air, ventilation
- Pumps
- Living quarters & workshops
- Essential supplies
- Gas turbine auxiliary supplies

The LV switchboard is located in the Local Equipment Room (SWR-LER)

6.1.4 Local Equipment Room

A Local Electrical Room (LER) will be required on the platforms to house the main LV Switchboards and equipment control panels.

6.1.5 Gas Turbine Generator Auxiliaries & Control panels

The control panels and LV (415v) switchgear for supplying LV Feeds for each of the gas and steam turbines as well as the expander turbines will be located in a separate single Control Cabin (CC) that will be located adjacent to the gas turbines.

6.1.6 Emergency Power

In event of loss of power from the main 11kV system a stand-by diesel generator located in an auxiliary generator room (AR) will supply the LV system. Vital loads will be supported by a UPS (Uninterrupted Power Supply). In case of power loss or black start-up auxiliary power will be required, which will be provided.

6.1.7 Design Life

Electrical equipment shall have a minimum design life of 20 years, under the specified service conditions. All equipment shall be brand new and of recent manufacture.

6.1.8 Design Codes

All future design work will be in accordance with the National Grid Security and Quality of Supply Standards.

6.2 Electrical Equipment Data (Option 2 & 3)

6.2.1 Electric Generators (Option 2 & 3)

Option	PFD Tag No Ref	Description	Gen Type	Power (MW)	Voltage (kv)	Frequency (Hz)	Cooling Method
2 (Cryo)	K-4-101	Gas Turbine Generator	Sync	86	11	50	TBC
	K-4-102	Gas Turbine Generator	Sync	86	11	50	TBC
	K-4-100	Steam Turbine Gen	Sync	22	11	50	TBC
	K-5-100	Steam Turbine Gen	Sync	56	11	50	TBC
3 (Oxy Fuel)	K-2-1-100	Gas Turbine Generator	Sync	68	11	50	TBC
	K-2-1-101	Gas Turbine Generator	Sync	65	11	50	TBC
	K-2-2-100	Gas Turbine Generator	Sync	68	11	50	TBC
	K-2-2-101	Gas Turbine Generator	Sync	65	11	50	TBC
2 & 3	N/A	Standby Diesel Generator	Sync	0.5 (MVA)	0.4	50	TBC

Table 19: Electrical Generators Options 2 7 3

6.2.2 Transformers (Options 2 & 3)

Option	SLD Tag Ref No	No Required	Description	Voltage (kv)	Frequency (Hz)	Power (MVA)	Length (m)	Width (m)	Height (m)	Weight (MT)
2	SLD 2	4	MV/HV Step Up Transformer	11/132	50	75	8.6	7.6	7.4	120
	SLD 2	2	MV/LV Step Down Transformer	11/0.4	50	2	2.5	2.5	2	5.5
3	SLD 3	4	MV/HV Step Up Transformer	11/132	50	75	8.6	7.6	7.4	120
	SLD 3	2	MV/LV Step Down Transformer	11/0.4	50	2	2.5	2.5	2	5.5

Table 20: Equipment Data_Transformers (options 2 & 3)

6.2.3 Switchgear and Local Equipment Modules (options 2 & 3)

Option	**Description**	**No**	**Length (m)**	**Width (m)**	**Height (m)**	**Weight (kg)**	**Switchboards Installed**	**Switchgear Type**	**No of Breaker Bays**
2&3	HV Switch room	1	10.5	8.5	5	22,000	HV (132KV)	GIS	9
	MV Switch room	1	10	5	4	22,000	5 x MV (11kv)	Vacuum	20
	LER Switch room	1	10	4	4	20,000	- 7 x LV (415v) - Various control/SCADA panels	Air	TBC
	Local Turbine Equipment Room	1	10	4	4	15,000	4	Air	TBC

Table 21: Electrical Switch Room Requirements (Option 2 & 3)

Note 1 (Table 23)**:** The Switch rooms will be fully Pressurized-Hazardous Area classification.

7 MATERIALS

The materials of the process equipment and piping will mainly be Carbon Steel or Stainless Steel based on the duty, strength requirements, pressure rating, temperature rating and corrosion resistance requirements. In general, the following will guide the material selection:

Material	General Usage Examples
A516 Carbon Steel	A516 is a pressure vessel quality steel plate intended for use in moderate or lower temperatures such as those vessels identified in Table 9 & Table 17
A285C Carbon Steel	A285C is a general grade carbon steel used when low or intermediate tensile strength is required. Examples of its uses are in boiler, pressure vessel steel, and pipes transporting hot liquids and Turbine shells.
A214 Carbon Steel	ASTM A214 Carbon Steel Tubing are mostly used for most of industrial applications. A214 Carbon Steel Heat-Exchanger & Condenser Tubes is often used in applications where rust resistance is critical and provides for extended durability than non-coated carbon steel for high performance at higher temperature.
316L Stainless Steel	Used in applications requiring corrosion protection such as process containing High levels of CO2 such as in the CO2. Stainless steel would also be used in low temperature (Cryogenic) whereby Carbon steel would be brittle and therefore unsuitable. For TIGRE™ Seals this would require stainless steel or stainless steel alloy to be used in Cryogenic Oxygen process (Option 3 Oxyfuel) and in the Cryogenic CO2 and N2 processes (Option 2 Cryocell).

Table 22: Material selection strategy

8 IDENTIFICATION OF HAZARDS

The following hazards have been identified that will need to be considered further in the FEED phase when optimising the design and layouts. These are specific hazards over and above the normal hazards of an offshore platform environment and when operating a gas production and power plant. An initial HAZID and HAZOP workshops will be undertaken at the FEED phase.

HAZARD	Mitigation/Follow UP
HV Equipment: The platform will contain electrical equipment operating at transmission system level voltages i.e., 132kv: - Explosion/Fire - Electrocution - Oil spills from transformers	• HV equipment transferred to OFTO for operation. • OFTO asset operators have experience in operating Transmission equipment. • Spacing and layout of HV equipment (especially transformers). • Containment tank to contain any oil spills.
Loss of containment of CO2 through leaks or blowdown: - Asphyxiation - Overpressure	• Undertake HAZOP at FEED phase. • Leak Detection. • Equipment selection. • Training of operators. • Ventilation.
(For Option 3) Loss of Containment of Liquid Oxygen: - Fire - Acute health Effects	• Undertake HAZOP at FEED phase. • Leak Detection. • Equipment selection. • Training of operators. • Ventilation.

Table 23: Identified Key Hazards

9 OPERATIONAL FACILITIES

Operational requirements for both Option 2 & 3 have been assessed at a high level with the requirements summarised below.

9.1 Level of Manning

With both Options there is a significant amount of specialised rotating equipment, deployment of developing technology combined with novel operating modes. It is therefore anticipated that the platform would be continually manned for the first few years. The concept therefore would be designed for a low-level continuous manning for Operations and first line maintenance. Annual Maintenance will be carried out on planned campaign basis. Table 24 outlines the estimated initial manning requirements estimated for normal operations for the first period of operations. Note OFTO personnel will require access to the HV system on an adhoc basis.

For campaign maintenance it is assumed that additional personnel will be located on board or on a commissioned accommodation vessel that will be stationed adjacent to the platform whereby personnel would access the platform via a linked bridge allowing workers to “walk to work”.

Further work during the FEED will look to confirm manning requirements and where possible reduce.

Position	No	Role
Operator Technician (Electrical)	2	Undertaking Electrical switching/isolations and first line electrical maintenance
Operator technician (Mechanical)	2	Undertaking first line mechanical maintenance and operations support
Operator technician (Instruments)	2	Undertaking first line Instrument fault finding, maintenance and operations support
Operator Control Room	1	Provide Control room oversight and perimetry control
Accommodation Steward/Cook	2	Provide general stewarding and meals
General Assistant	1	Provide general assistance support to technicians.

Table 24: Estimated Permanent Manning levels

9.2 Operational and Maintenance Requirements

9.2.1 Living Quarters

The A60 rated living quarters will provide permanent accommodation for the permanent operations and maintenance crew with a contingency of 4 more rooms provided for additional adhoc maintenance requirements (i.e., including OFTO personnel). This would mean a total of 14 rooms.

All rooms will normally be occupied on a single basis but will include bunk bed to accommodate 4 persons per room (total POB of 36) on an emergency basis i.e., if maintenance crew stranded on board overnight. The Living quarters would include the following facilities.

- Control Room.
- Sleeping quarters.
- MessRoom/Kitchen/Recreation room.
- Domestic services such as laundry.
- Changing Room.
- First Aid.

Figure 6 illustrates the possible layout for the Accommodation block.

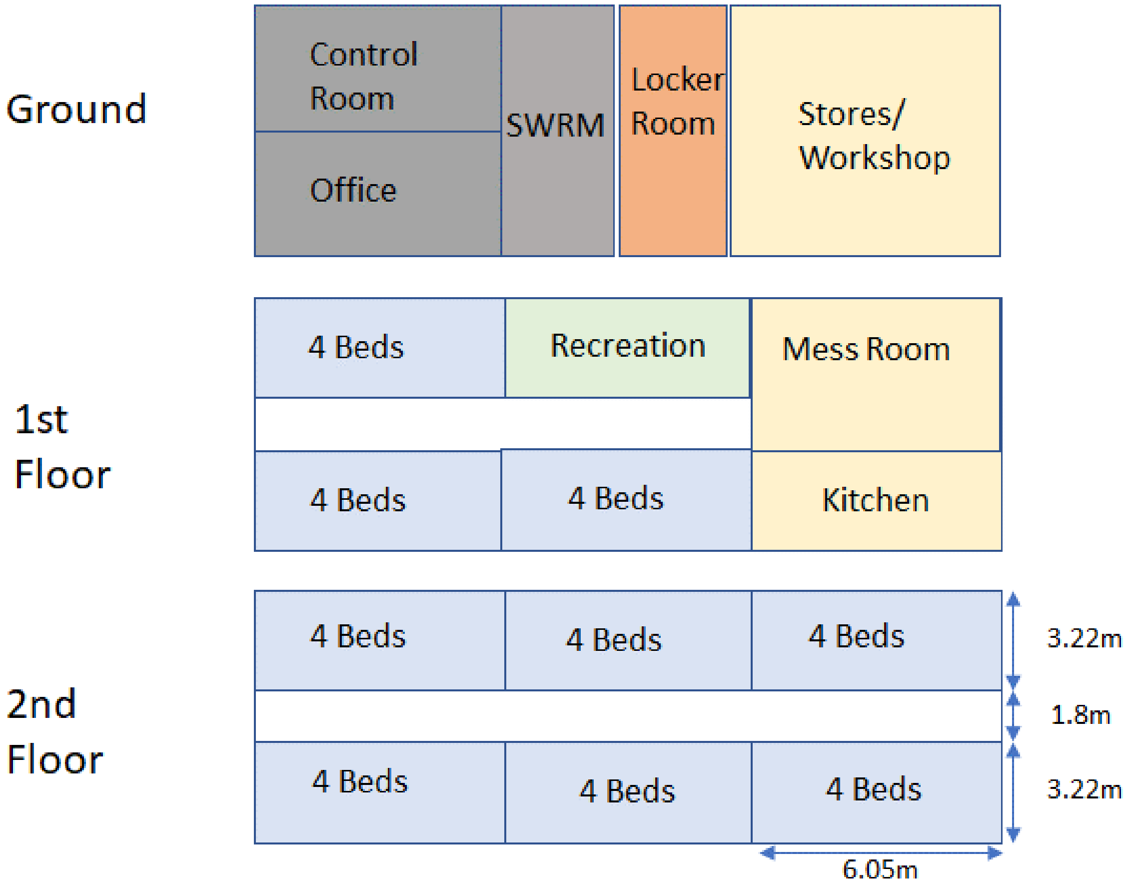


Figure 6: Assumed Accommodation Block layout (Plan view of 3 Floors)

9.2.2 Access Facilities

Access will depend upon location of the platform and therefore be further defined during FEED. The project base case assumes a walk to work access system whereby personnel are transferred to the platform by boat.

Two access points will be located on opposite sides of the platform so that access conditions can be maintained during different prevailing wind and wave conditions.

9.2.3 Craneage

An electrohydraulic Pedestal Crane to lift equipment on and off the platform. It is assumed that a maximum of 2tonnes lifting capacity would be sufficient with larger items being lifted on/off the platform via a lifting vessel that would locate adjacent to the platform. This requires to be fully reviewed during FEED.

9.2.4 Laydown Facilities

Laydown facilities on the deck will be required for lifting equipment on an off the platform and between decks. A laydown facility is required on each deck.

9.3 Technical Safety

9.3.1 Firefighting

The platform will contain active firefighting measures such as deluge/sprinkler systems to cover accommodation and /or systems such as Compressed Air Foam System (CAFS) and an inert gas such as an INERGEN package. Although firefighting systems will require space (often separate modules for drivers) the requirements have not been studied at feasibility but is identified to be covered at the FEED phase.

9.3.2 Emergency Evacuation

The primary routes to leave the platform will be via:

- Walk to Work (Boat Access)
- Bridge Access to adjacent gas production platform

If these routes were not available in an emergency, then evacuation from the platform will be via a davit launched inflatable life raft which will be deployed via a davit winch. It is expected that two will be required at opposite sides of the platform with the locations considering prevailing wind/wave direction and (any) adjacent location of gas production platform.

10 TOPSIDE PLATFORM WEIGHT REGISTER

A summary of the project topside weight requirement is included in the weight registers in Table 25 (Option 2) and Table 26 (Option 3). These tables list the main equipment Items that are tagged in the PFDs and SLDs along with the key modules identified such as electrical switch-rooms and Accommodation module.

Equipment bulk weights for piping and instrumentation are then estimated from the main tagged equipment by applying established norms.

A full module design has not been undertaken at the feasibility stage. Therefore, an estimate has been determined based on the amount of secondary and primary steelwork likely required for the topside module.

In accordance with TiGRE's experience, it is estimated that the amount of Structural Steelwork applied is around 34% of the equipment weight.

The next Phase FEED study should develop further the weight register list by:

- ➢ Studying areas that were outside of the scope of the feasibility study such as:
  - Firefighting requirements
  - Identifying HVAC requirements
  - Piping sizes and routes
  - Developing the process for blowdown and drains systems
  - Developing requirements for bulk storage
- ➢ Engaging with key supplier's re-equipment data sheets.
- ➢ Further optimisation of the process and electrical system

For tables 25 and 26 the following should be noted:

Note 1 Table 26: Option 3 Weight **:** For the Gas Turbine/generators the weight of a standard OCGT has been used as a reference for wight (250MT) and size. As the oxyfuel gas generator will not require an air compressor the weight has been reduced by one third to provide an approximate weight of the remaining combustion chamber, power turbine and electric generator.

Note 2 (Table 25): A standard OCGT package has been used as the reference point for weight and dimensions of the gas turbines although an assessment has been made on how these would be reduced to reflect the TiGRE™ SEALS concept.

Note 3 (Table 26 & Table 26 **):** The weight and dimensions numbers in Italics are TIGRE™ educated estimates based on experience. All other figures are supplied as a HYSYS output.

Note 4 (Table 25 & Table 26): The layout drawing reference is where each individual equipment item is shown on the layout drawings (Appendices 6 & 7).

Layout Drawing Reference	PFD /SLD Ref	Tag No	Component/Source	Weight (KG)	L (mm)	W(mm)	H (mm)
1	1	E-1-100	FG Cooler	14,288	6,000	575	
2	4	E-4-101	Steam Cond	31,431	6,000	1,425	
3	5	E-5-100	Seawater Condensor	89,115	6,000	1,675	
4	5	E-5-102	ExG SW cooler	62,504	6,000	1,550	
5	5	E-5-103	ExG Recycle Comp discharge HE	9,808	6,000	450	
6	6	E-6-100	H2O/N2 HE	165,041	6,000	1,375	
7	6	E-6-101	N2/N2 HE	46,987	6,000	950	
8	6	E-6-102	N2/N2 HE	42,954	6,000	1,075	
9	7	E-7-100	ExG Compressoe Inlet Precooler	14,848	6,000	625	
10	7	E-7-101	ExG Compressor 1 Discharge HE	169,726	6,000	1,200	
11	7	E-7-102	ExG SW Precooler	17,915	6,000	925	
12	7	E-7-104	ExG HE	19,946	6,000	1,050	
13	8	E-8-100	ExG/Co2 HE	7,009	6,000	350	
14	8	E-8-101	ExG / N2 HE	36,927	6,000	1,700	
15	8	E-8-102	ExG / N2 HE	14,409	6,000	650	
16	8	E-8-103	ExG / N2 HE	46,928	6,000	1,425	
17	8	E8-104	ExG / Co2 HE	7,096	6,000	350	
18	1	K-1-100	Fuel Gas Compressor	93,617	*12,900*	*4,500*	*5,000*
19	6	K-6-100	N2 refrig comp	171,501	*20,000*	*5,000*	*5,000*
20	7	K-7-101	Cryo Comp 2	178,162	*20,000*	*5,000*	*5,000*
21	4	P-4-110	Condensed Water Feed Pump	167,179	*20,000*	*5,000*	*5,000*
22	5	P-5-100	HP Water FEED Pump	180,213	*20,000*	*5,000*	*5,000*
23	8	P-8-100	CO2 Well Injection Pump	5,322	*5,000*	*3,000*	*3,000*
24	5	V-5-100	Exhaust Gas H2O Seperator	189,041	*11,278*	*3,810*	
25	7	V-7-100	Exhaust Gas Comp 1 Discharge H20 KO Drum	41,944		*3,800*	*6,096*
26	8	V-8-100	Exhaust Gas Comp 2 Discharge H20 KO Drum	38,454		*4,572*	*3,810*
27	8	V-8-101	Solid CO2 Separation Vessel	36,895		*4,115*	*3,800*
28	2	GT-1	Gas Turbine (k-2-100 /GBR-2-100 /K-2-101)	170,000	20	5	5
29	3	GT-2	Gas Turbine (k-3-100 /GBR-3-100 /K-3-101)	170,000	20	5	5
30	4	Gen 1	Gas Turbine Generator (GBR-4-100 /K-4-101)	170,000	20	5	5
31	4	Gen 2	Gas Turbine Generator (GBR-4-100 /K-4-102)	170,000	20	5	5
32	4	K-4-100	HP Steam turbine Genertor	265,000	20	5	5
33	5	K-5-101	LP Steam turbine Genertor	265,000	20	5	5
34	SLD 1	TX-1-100	132kv/75MVA Transformer	120,000	8,600	7,600	7,500
35	SLD 1	TX-1-101	132kv/75MVA Transformer	120,000	8,600	7,600	7,500
36	SLD 1	TX-2-100	132kv/75MVA Transformer	120,000	8,600	7,600	7,500
37	SLD 1	TX-2-101	132kv/75MVA Transformer	120,000	8,600	7,600	7,500
38	SLD 1	TX-3-100	11kv 500kVA Transformer	5,500	2,500	2,500	2,000
39	SLD 1	TX-3-101	11kv 500kVA Transformer	5,500	2,500	2,500	2,000
40	SLD 1	AR	Auxilliary generator Room	10,500	7,500	3,000	4,000
41	SLD 1	SWR-HV	High Voltage Switch Room	25,000	10,500	8,500	7,500
42	SLD 1	SWR-MV	Medium Voltage Switch Room	22,000	10,000	5,000	4,000
43	SLD 1	SWR-LER	Local Equipment Room	20,000	6,200	4,400	4,000
44	N/A	N/A	Accomodation/Office/Control roo/Workshop/Stores	9,000	18,150	8,250	18,000
45	N/A	N/A	laydown Area (Top Deck)		3,000	3,000	
Total main Tagged Equipment Weight (kg)				3,686,760			
Bulks (piping/Instrumentation etc) & 10% Tagged Equipment Weight				368,676			
Topsides Module Primary & Secondary Steel @34% of Equipment + Bulks Weight				1,378,848			
Total Topsides Module Weight (DRY)				5,434,284			

Table 25: Option 2 Weight Register

Layout Drawing Reference	PFD/ SLD Ref	Tag No	Component/Source	Equipment Weight (kg)	L(mm)	W(mm)	H(mm)
1	PB2	V-2-100	CO2/Produced Water Seperator	17,600	9,400	3,200	
2	PB2	P-2-101	Produced Water Booster Pump	9,000	*4,000*	*3,000*	*4,000*
3	PB2	P-2-100	LOX booster pump	3,200	*4,000*	*3,000*	*4,000*
4	PB2	K-2-100	Fuel gas compressor	76,500	12,900	4,500	5,000
5	PB2	E-2-101	Exhaus Gas HE	97,400	7,500	3,000	
6	PB2	E-2-100	LOX feed preheate	8,500	6,000	725	
7	PB2-2	E-2-2-100	Steam Generator (Train 2)	348,300	6,000	1,625	
8	PB2-1	E-2-1-100	Steam Generator (Train 1)	348,300	6,000	1,625	
9	PB3	V-100	2nd Stage CO2 Compressor discharge KO drum	5,800	3,800	2,100	
10	PB3	K-3-102	3rd Stg CO2 comp	21,200	*6,000*	*3,000*	*3,000*
11	PB3	K-3-101	2nd Stg CO2 Comp	17,300	*6,000*	*3,000*	*3,000*
12	PB3	K-3-100	1st Stg CO2 Comp	*20,000*	*6,000*	*3,000*	*3,000*
13	PB3	E-3-101	1st Stage CO2 Compressor discharge HE	2,200	6,000	450	
14	PB3	E-3-100	3nd Stage CO2 compressor Discharge HE	27,900	6,000	1,300	
15	PB3	E-100	2nd Stage CO2 Compressor Discharge Cooler	2,400	6,000	450	
16	PB3		2nd Stage water sep_@CS	2,900	3,800	2,100	
17	PB1	K-1-101	ASU MAC Stg2	137,400	*15,000*	*6,000*	*6,000*
18	PB1	K-1-100	ASU MAC Stg1	271,400	*15,000*	*6,000*	*6,000*
19	PB1	E-101	MAC 1st Stage Discharge Cooler	106,800	6,000	1,825	
20	PB1	E-100	MAC Cooler	428,800	6,000	1,825	
21	PB1	E-1-100	MAC 2nd Stage Discharge Cooler	67,500	6,000	1,675	
22	PB4	P-4-103	Cooling water booster pump	1,500	*2,000*	*2,000*	*2,000*
23	PB4	P-4-102	Cooling water booster pump	1,200	*2,000*	*2,000*	*2,000*
24	PB4	P-4-101	Cooling Water Booster pump	1,700	*2,000*	*2,000*	*2,000*
25	PB4	P-4-100	Submersible SW lift pump	15,400	*6,000*	*3,000*	*3,000*
26	PB4	E-4-102	ASU coling water HE	260,700	8,000	739	
27	PB4	E-4-101	CO2 Compressor cooling water HE	45,200	8,000	739	
28	PB4	E-4-100	OXY Fuel Comb SW	266,100	8,000	739	
29	PB1	UC-reboiler_	UC-reboiler_@COL-1-100 A(ID:75)	3,200	4,000	1,000	
30	PB1	UC trays_@CO	UC trays_@COL-1-100 ASU(ID:76)	159,900		5,800	27,000
31	PB1	LR-CD_@COL-1	LR-CD_@COL-1-100 ASU Fra(ID:78)	3,500	5,940	1,980	
32	PB1	LR-CD_@COL-1	LR-CD_@COL-1-100 ASU Fra(ID:80)	650	*2,000*	*2,000*	*2,000*
33	PB1	LR column_@C	LR column_@COL-1-100 ASU(ID:81)	63,300		3,100	27,000
34	PB1	LC-trays_@CO	LC-trays_@COL-1-100 ASU(ID:82)	52,200		4,900	8,700
35	PB1	LC-CD_@COL-1	LC-CD_@COL-1-100 ASU Fra(ID:84)	11,000	9,300	2,900	
36	PB1	LC-CD_@COL-1	LC-CD_@COL-1-100 ASU Fra(ID:86)	1,300	*2,000*	*2,000*	*2,000*
37	SLD 2	G-1-100	Gas Turbine/generator	170,000	20	5	5
38	SLD 2	G-1-101	Gas Turbine/generator	170,000	20	5	5
39	SLD 2	G-2-101	Gas Turbine/generator	170,000	20	5	5
40	SLD 2	G-1-102	Gas Turbine/generator	170,000	20	5	5
41	SLD 2	TX-1-100	132kv/75MVA Transformer	120,000	*8,600*	*7,600*	*7,500*
42	SLD 2	TX-1-101	132kv/75MVA Transformer	120,000	*8,600*	*7,600*	*7,500*
43	SLD 2	TX-2-100	132kv/75MVA Transformer	120,000	*8,600*	*7,600*	*7,500*
44	SLD 2	TX-2-101	132kv/75MVA Transformer	120,000	*8,600*	*7,600*	*7,500*
45	SLD 2	TX-3-100	11kv 500kVA Transformer	5,500	*2,500*	*2,500*	*2,000*
46	SLD 2	TX-3-101	11kv 500kVA Transformer	5,500	*2,500*	*2,500*	*2,000*
47	SLD 2	AR	Auxilliary generator Room	10,500	*7,500*	*3,000*	*4,000*
48	N/A	SWR-HV	High Voltage Switch Room	25,000	*10,500*	*8,500*	*7,500*
49	N/A	SWR-MV	Medium Voltage Switch Room	22,000	*10,000*	*5,000*	*4,000*
50	N/A	SWR-LER	Local Equipment Room	20,000	*6,200*	*4,400*	*4,000*
51	N/A		Accomodation/Office/Control roo/Workshop/Stores	9,000	*18,150*	*8,250*	*18,000*
52	N/A		laydown Area (Top Deck)		*3,000*	*3,000*	
Total main Tagged Equipment Weight (kg)				*4,155,750*			
Bulks (piping/Instrumentation etc) & 10% Tagged Equipment Weight				*415,575*			
Topsides Module Primary & Secondary Steel @34% of Equipment + Bulks Weight				*1,554,251*			
Total Topsides Module Weight (DRY)				*6,125,576*			

Table 26: Option 3 Weight Register

11 LAYOUTS

An initial layout for Options 2 & 3 has been undertaken and are shown in Appendix 6 (Option 2 Layout) and Appendix 7 (Option 3 Layout). The purpose of these layouts is to provide an illustration of the likely topside platform arrangement, in terms of its key dimensional requirements (length, width and height).

For the purposes of the feasibility study, the layouts have been undertaken by considering only the key tag equipment Items identified in tables Table 25 and Table 26.

The following areas were considered in the proposed layout:

Centre of Gravity: An assessment of the centre of gravity of each tagged equipment item and the topside module has not been made at this stage but will require to be a key input into finalising the topside layouts.

Safety: The layouts considered at a preliminary high level the location of equipment into hazardous zones. The 3 zones considered include:

Zone Classification	Definition	Equipment Type Located
Non-Hazardous	Areas normally free from Hydrocarbons	- Accommodation - Switch rooms - Local Equipment Rooms - Gas Turbine Generators
Hazardous	Hydrocarbon Areas	- Fuel gas Compressors - Produced Water - Heat Exchangers - Hydrocarbon Pumps
OFTO	Equipment to be adopted by the OFTO	-132kv Electrical Equipment

Table 27: Zone Classifications for Equipment layouts

Prevailing wind: A prevailing wind direction has been assumed and the platform orientated so that the air intakes and equipment are aligned for maximum cooling and ventilation.

Maintenance: Preliminary consideration has been given to allow for key equipment items to be lifted in and out of the module by lifting vessels. The layout has therefore ensured key items are accessible by lifting crane vessel. These key items are:

- Gas Generators: Maintenance space is required for either servicing to be undertaken offshore or for the gas turbine to be sent onshore for major service.
- Compressors: Compressors can be de assembled on-site and key equipment items serviced or changed out. The space required for removal of the gas turbines is also used as the minimal space required to allow the compressors to be removed.
- Transformers. The Transformers are assumed to be oil-filled and therefore would require to be lifted off in a single lift if needing to be replacement.

11.1 Option 3 Layout

The layout shown in Appendix 7 has the topsides organised as follows:

Cellar Deck: Contains the oxyfuel gas turbines, the steam generator (heat exchangers) and fuel gas compressor located at the opposite side of the platform to the accommodation unit.

Module Deck: Contains the 1st floor of the accommodation unit which includes the stores, changing rooms, workshop, offices etc. The accommodation unit is located on the up-wind side of the platform so that any gases leaked will mainly blow away from the accommodation. At the other end of the module deck is located the CO2 handling plant including CO2 compressors, knock out drums and heat exchangers. Located between the accommodation block and the CO2 equipment is the Air Supply Unit.

Top Deck: The electrical switchgear is mainly located on this deck with all the 132kv Transformers and switch room located at one side so that the appointed OFTO can easily access their offshore substation. Located at the opposite side of the Top deck is the 2nd and 3rd floors of the accommodation module which is mainly the sleeping quarters and the kitchen/messroom and recreational room. In between the 132kv Transformers and the accommodation block is located the MV and LV switchrooms and Standby Generator.

12 PLATFROM JACKET FOUNDATION AND MODULE STRUCTURE

12.1 Module Structure

Whilst there is a significant amount of work needed to finalise the layouts following further design development, the output from the feasibility study indicates that a minimum deck area of 3 decks each of approximately 60m by 25m would be required. A height of around 9m between decks is also assumed.

12.2 Foundation jacket

The foundation for the topsides is assumed to be either a 4 or 6-legged jacket with a weight of approximately 1500 to 2000 MT. This is based on 30% of the topside weight. The foundation weight would be expected to be made up approximately 50% Jacket structure with 50% piles and appurtenances.

13 CONSTRUCTION

The appropriate strategy for constructing the Project will be determined during FEED following engagement with typical construction contractors. At the feasibility phase a construction strategy has been assumed as a basis for developing the project CAPEX costs and confirming project feasibility. The construction strategy is based on the following.

- The topsides module will be fabricated as a single module at an onshore fabrication yard with equipment items being delivered to the facility for insertion onto the module. Typical facilities are available on the East Coast of the UK and on the Continent across the SNS.
- The Jacket foundation would also be fabricated at a suitable onshore fabrication facility.
- The jacket foundation would be skidded onto a barge and transported to the offshore site whereby it will be lifted from the transport barge by a heavy lift crane and place upright onto the seabed. Piles would then be used to pin the foundation to the seabed.
- The fabricated topside once completed will also be skidded onto a barge and transported to the site whereby it will be lifted off the barge and placed on top of the pre-installed foundation jacket in a single lift by a suitable heavy lift vessel.
- The power cables to connect the platform to the onshore grid and the fuel gas supply lines from the adjacent gas production platform can be installed/pulled in once the topside is in place.
- The jacket foundation is expected to weigh around 1500 to 2000Tonnes. This is within the lifting capability of offshore lifting vessels.
- The Topside Platform to be installed is estimated to weigh around 6000tonnes and would therefore require a vessel that could lift at least 7000-10,000 tonnes to do in a single lift.

- Options to investigate at the FEED stage would be to undertake the topside lift in more than 1 lift or to split the scope into 2 modules whereby part of the topsides (i.e., the OFTO Assets) is mounted as a separate topside onto its own separately installed foundation.
- The project requires to liaise with the OFTO at the windfarm offshore substation and the gas production operator to ensure tie ins to their systems are complete with minimal interruption and in a time that does not delay the project.
- A Construction HAZID would identify specific construction risks that would need to be managed such as lifting and anchoring adjacent to operating pipelines.

14 REFERENCES

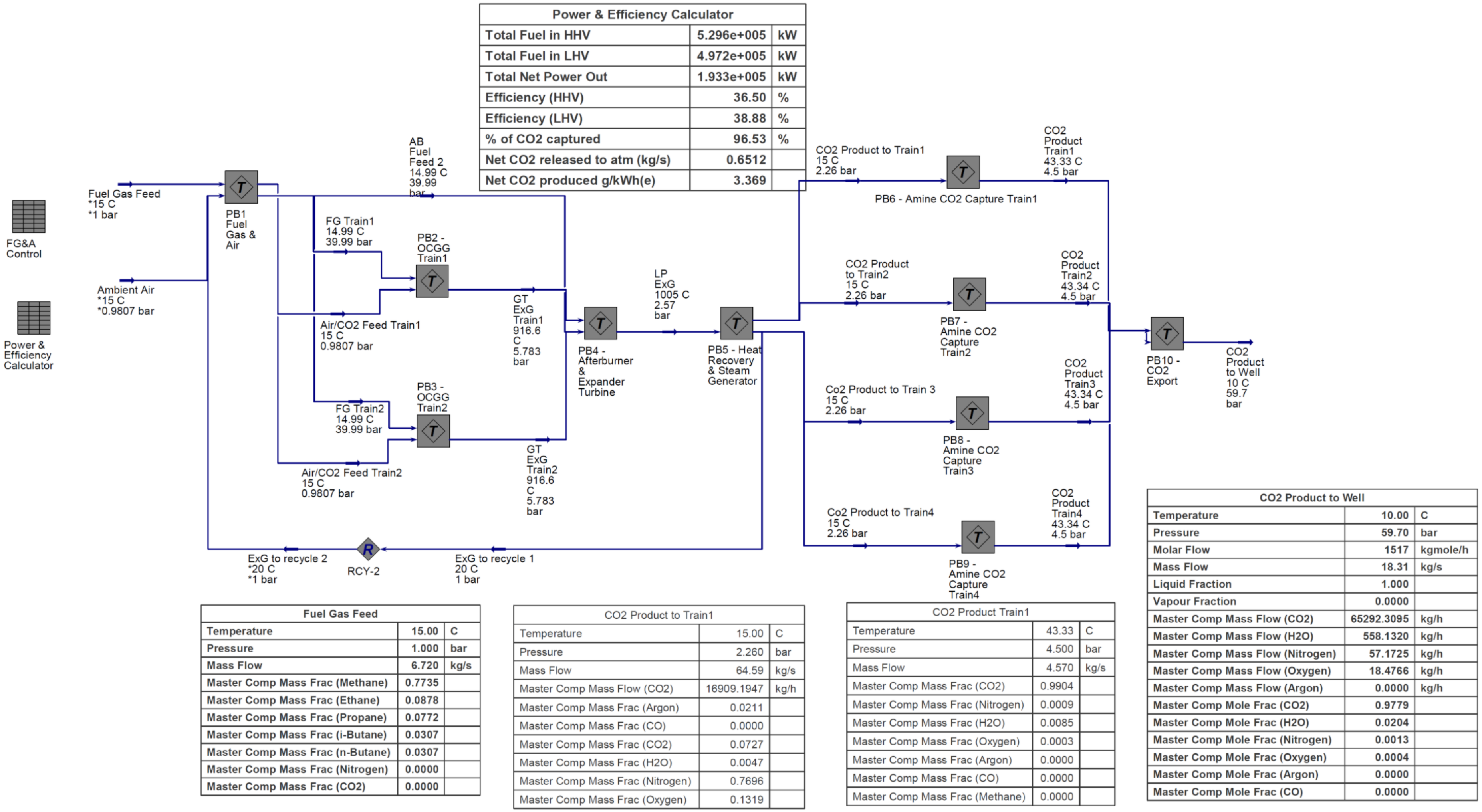
Feasibility Study _Reservoir Behavioural Characterisation & Analysis under TiGRE™ & CCUS Conditions_17th Dec 2019.

TiGRE Technologies Limited CS362 Feasibility Study Report and Recommendations (March 16th, 2020).

TiGRE Technologies Limited CS362 Milestone 2 Submission slide pack (January 24th 2020).

15 APPENDICES

Appendix 1: Process Flow Diagrams (Option 1)



Power & Efficiency Calculator		
Total Fuel in HHV	5.296e+005	kW
Total Fuel in LHV	4.972e+005	kW
Total Net Power Out	1.933e+005	kW
Efficiency (HHV)	36.50	%
Efficiency (LHV)	38.88	%
% of CO2 captured	96.53	%
Net CO2 released to atm (kg/s)	0.6512	
Net CO2 produced g/kWh(e)	3.369	

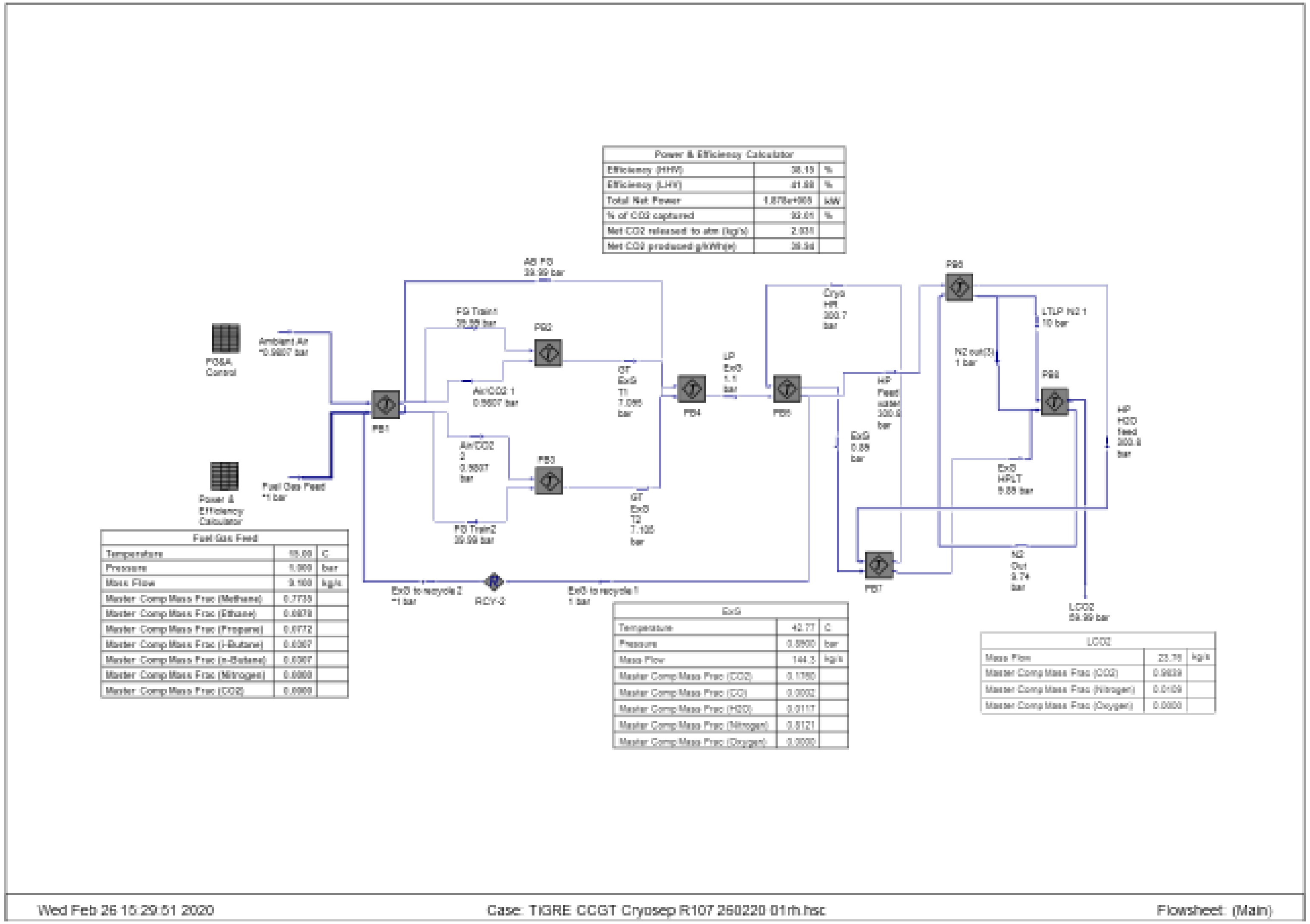
Fuel Gas Feed		
Temperature	15.00	C
Pressure	1.000	bar
Mass Flow	6.720	kg/s
Master Comp Mass Frac (Methane)	0.7735	
Master Comp Mass Frac (Ethane)	0.0878	
Master Comp Mass Frac (Propane)	0.0772	
Master Comp Mass Frac (i-Butane)	0.0307	
Master Comp Mass Frac (n-Butane)	0.0307	
Master Comp Mass Frac (Nitrogen)	0.0000	
Master Comp Mass Frac (CO2)	0.0000	

CO2 Product to Train1		
Temperature	15.00	C
Pressure	2.260	bar
Mass Flow	64.59	kg/s
Master Comp Mass Flow (CO2)	16909.1947	kg/h
Master Comp Mass Frac (Argon)	0.0211	
Master Comp Mass Frac (CO)	0.0000	
Master Comp Mass Frac (CO2)	0.0727	
Master Comp Mass Frac (H2O)	0.0047	
Master Comp Mass Frac (Nitrogen)	0.7696	
Master Comp Mass Frac (Oxygen)	0.1319	

CO2 Product Train1		
Temperature	43.33	C
Pressure	4.500	bar
Mass Flow	4.570	kg/s
Master Comp Mass Frac (CO2)	0.9904	
Master Comp Mass Frac (Nitrogen)	0.0009	
Master Comp Mass Frac (H2O)	0.0085	
Master Comp Mass Frac (Oxygen)	0.0003	
Master Comp Mass Frac (Argon)	0.0000	
Master Comp Mass Frac (CO)	0.0000	
Master Comp Mass Frac (Methane)	0.0000	

CO2 Product to Well		
Temperature	10.00	C
Pressure	59.70	bar
Molar Flow	1517	kgmole/h
Mass Flow	18.31	kg/s
Liquid Fraction	1.000	
Vapour Fraction	0.0000	
Master Comp Mass Flow (CO2)	65292.3095	kg/h
Master Comp Mass Flow (H2O)	558.1320	kg/h
Master Comp Mass Flow (Nitrogen)	57.1725	kg/h
Master Comp Mass Flow (Oxygen)	18.4766	kg/h
Master Comp Mass Flow (Argon)	0.0000	kg/h
Master Comp Mole Frac (CO2)	0.9779	
Master Comp Mole Frac (H2O)	0.0204	
Master Comp Mole Frac (Nitrogen)	0.0013	
Master Comp Mole Frac (Oxygen)	0.0004	
Master Comp Mole Frac (Argon)	0.0000	
Master Comp Mole Frac (CO)	0.0000	

Appendix 2: Process Flow Diagrams (Option 2)



Power & Efficiency Calculator		
Efficiency (HHV)	38.15	%
Efficiency (LHV)	41.88	%
Total Net Power	1.878e+005	kW
% of CO2 captured	92.61	%
Net CO2 released to atm (kg/s)	2.031	
Net CO2 produced g/kWh(e)	38.94	

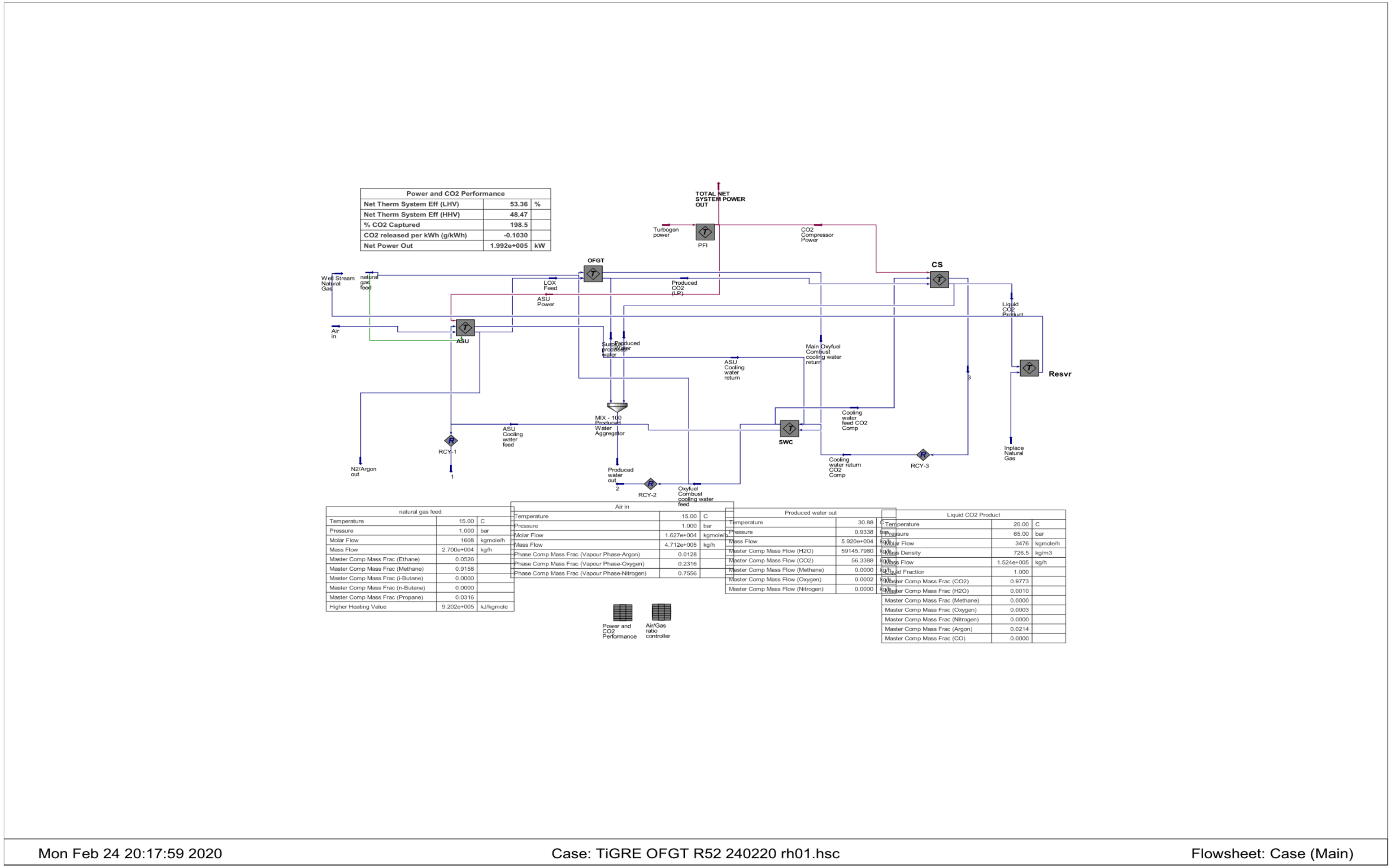
Fuel Gas Feed		
Temperature	15.00	C
Pressure	1.000	bar
Mass Flow	9.100	kg/s
Master Comp Mass Frac (Methane)	0.7735	
Master Comp Mass Frac (Ethane)	0.0878	
Master Comp Mass Frac (Propane)	0.0772	
Master Comp Mass Frac (i-Butane)	0.0307	
Master Comp Mass Frac (n-Butane)	0.0307	
Master Comp Mass Frac (Nitrogen)	0.0000	
Master Comp Mass Frac (CO2)	0.0000	

ExG		
Temperature	42.77	C
Pressure	0.9500	bar
Mass Flow	144.3	kg/s
Master Comp Mass Frac (CO2)	0.1750	
Master Comp Mass Frac (CO)	0.0002	
Master Comp Mass Frac (H2O)	0.0117	
Master Comp Mass Frac (Nitrogen)	0.8121	
Master Comp Mass Frac (Oxygen)	0.0000	

LCO2		
Mass Flow	23.79	kg/s
Master Comp Mass Frac (CO2)	0.9839	
Master Comp Mass Frac (Nitrogen)	0.0109	
Master Comp Mass Frac (Oxygen)	0.0000	

Wed Feb 26 15:29:51 2020 Case: TIGRE CCGT Cryosep R107 260220 01rh.hsc Flowsheet: (Main)

Appendix 3: Process Flow Diagrams (Option 3)



Power and CO2 Performance		
Net Therm System Eff (LHV)	53.36	%
Net Therm System Eff (HHV)	48.47	
% CO2 Captured	198.5	
CO2 released per kWh (g/kWh)	-0.1030	
Net Power Out	1.992e+005	kW

natural gas feed		
Temperature	15.00	C
Pressure	1.000	bar
Molar Flow	1608	kgmole/h
Mass Flow	2.700e+004	kg/h
Master Comp Mass Frac (Ethane)	0.0526	
Master Comp Mass Frac (Methane)	0.9158	
Master Comp Mass Frac (i-Butane)	0.0000	
Master Comp Mass Frac (n-Butane)	0.0000	
Master Comp Mass Frac (Propane)	0.0316	
Higher Heating Value	9.202e+005	kJ/kgmole

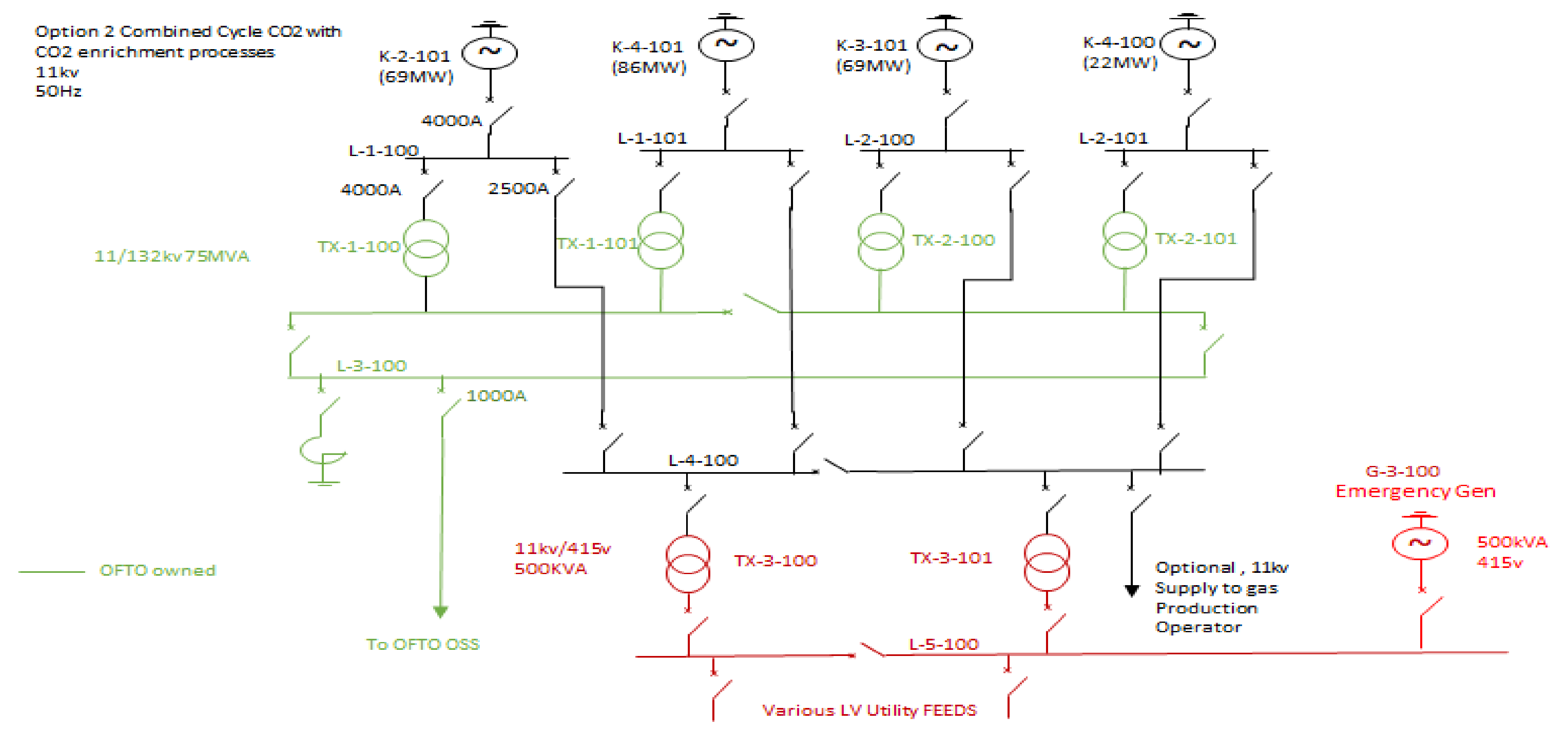
Air in		
Temperature	15.00	C
Pressure	1.000	bar
Molar Flow	1.627e+004	kgmole/h
Mass Flow	4.712e+005	kg/h
Phase Comp Mass Frac (Vapour Phase-Argon)	0.0128	
Phase Comp Mass Frac (Vapour Phase-Oxygen)	0.2316	
Phase Comp Mass Frac (Vapour Phase-Nitrogen)	0.7556	

Produced water out		
Temperature	30.88	C
Pressure	0.9338	bar
Mass Flow	5.920e+004	kg/h
Master Comp Mass Flow (H2O)	59145.7980	kg/h
Master Comp Mass Flow (CO2)	56.3388	kg/h
Master Comp Mass Flow (Methane)	0.0000	kg/h
Master Comp Mass Flow (Oxygen)	0.0002	kg/h
Master Comp Mass Flow (Nitrogen)	0.0000	kg/h

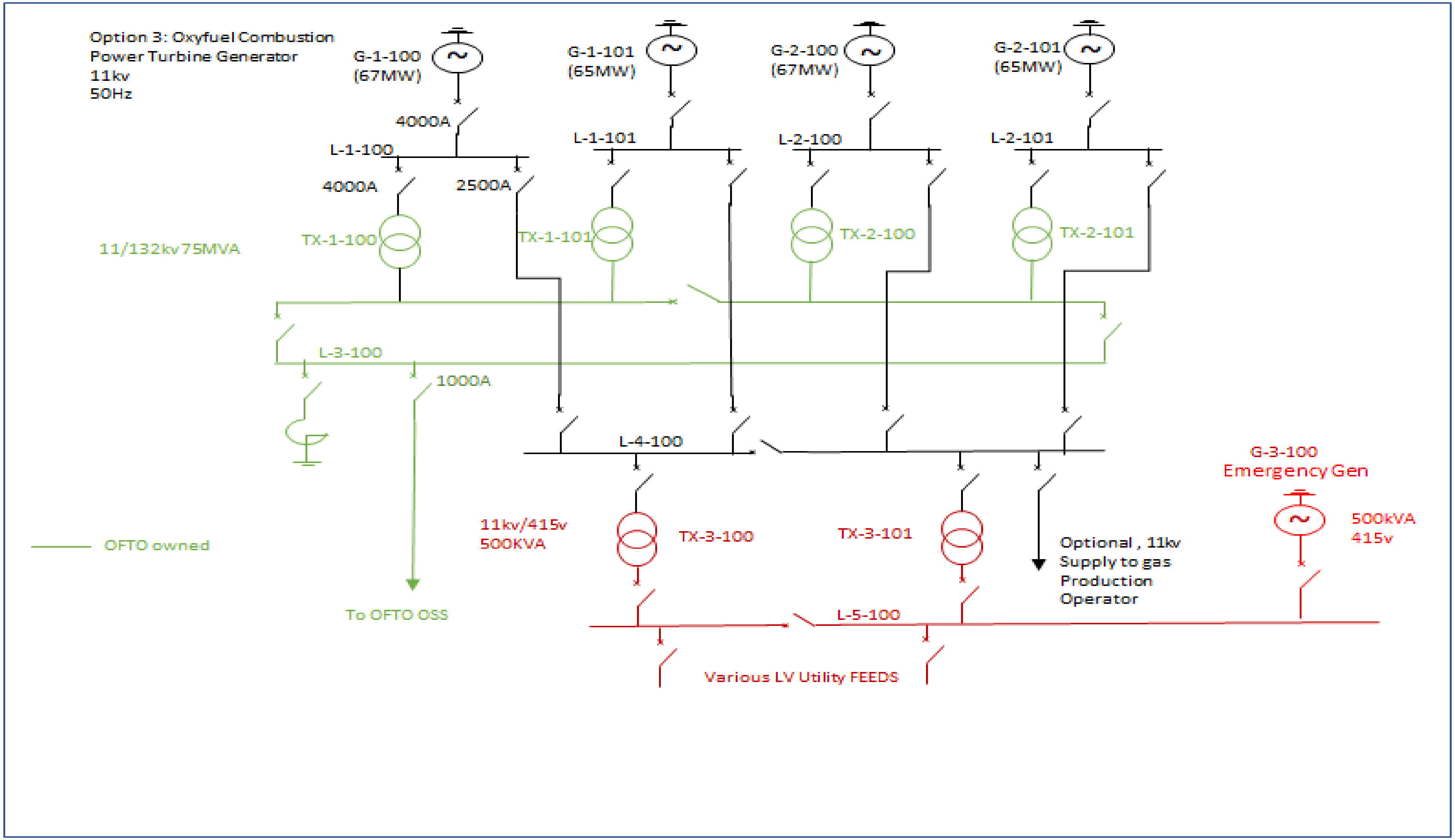
Liquid CO2 Product		
Temperature	20.00	C
Pressure	65.00	bar
Molar Flow	3476	kgmole/h
Mass Density	726.5	kg/m3
Mass Flow	1.524e+005	kg/h
Liquid Fraction	1.000	
Master Comp Mass Frac (CO2)	0.9773	
Master Comp Mass Frac (H2O)	0.0010	
Master Comp Mass Frac (Methane)	0.0000	
Master Comp Mass Frac (Oxygen)	0.0003	
Master Comp Mass Frac (Nitrogen)	0.0000	
Master Comp Mass Frac (Argon)	0.0214	
Master Comp Mass Frac (CO)	0.0000	

Mon Feb 24 20:17:59 2020 Case: TiGRE OFGT R52 240220 rh01.hsc Flowsheet: Case (Main)

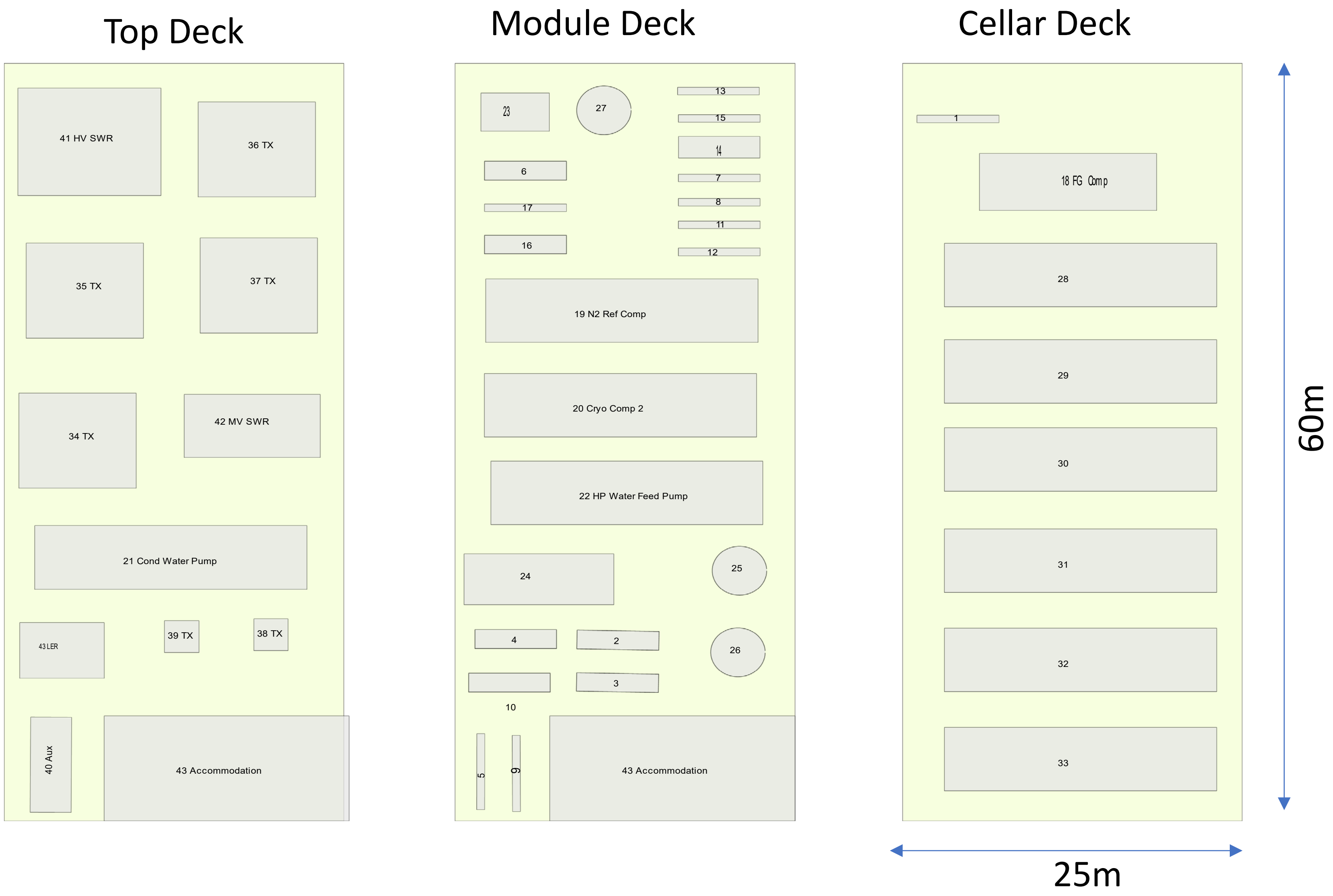
Appendix 4: Electrical Single Line Diagram (Option 2)



Appendix 5: Electrical SLD (Option 3)



Appendix 6: Layout Drawing (Option 2)



Appendix 7: Layout Arrangement Drawings (Option 3)