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Acorn CCS Project

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Produced by Pale Blue Dot Energy Ltd. (a Storegga Group company) as part of the BEIS CCUS Innovation Programme, these documents represent the suite of Key knowledge Deliverables produced during the Acorn CCS FEED Project under the Department of Business, Energy and Industrial Strategy (BEIS) Carbon Capture Utilisation and Storage (CCUS) Innovation Fund. The documents are reflective of the status of the project at the time of writing and are thus sequential and the material presented could have been subject to change as the project matured. These documents should not be considered a full representation of the final Acorn CCS project upon completion of FEED.

Document Title	Date Originally Issued	Document Title	Date Originally Issued
D02 Stakeholder Engagement and Communications Plan	31/08/2019	D12 Environmental Assessment (onshore)	
D24 Concept Options Report	08/11/2019	D13 Environmental Impact Assessment (offshore)	
D06 Permits & Consents Register	20/12/2019	D18 Risk Management Plan	
D11 Onshore Site Selection Report	28/02/2020	D21 Financing Plan	
D25 Concept Select Report	08/05/2020	D03 CO2 Capture Plant Design	
D10 Well Operating Guidelines	30/09/2020	D14 Economic Model & Report	
D08 Operations and Maintenance Philosophy	30/11/2020	D15 FEED Close-out Report	
D09 Well Design Report	30/11/2020	D16 FEED Lessons Learned Report	
D05 Storage Development Plan	31/03/2021	D17 Acorn CCS Development Plan & Budget	
D22 East Coast Deployment Report	31/03/2021	D19 Whole Chain Cost Estimate	
D04 Whole Chain BoD		D20 Project Schedule	
D07 Health, Safety and Environment Report		D23 Project Summary Report	

Signed by Storegga COO

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1.0 Executive Summary

The Acorn CCS project is a carbon capture and storage development project designed to capture an initial 300ktCO_2/yr from existing industrial emission sources at the St Fergus gas terminal complex in north east Scotland. The captured carbon dioxide (CO_2) would be conditioned, compressed, then transported offshore for storage in the Acorn CO_2 Storage Site via the existing 102km Goldeneye pipeline. The Acorn CCS project is led by Pale Blue Dot Energy (PBDE) along with industry partners (together, the Acorn parties).

The opportunity statement for the project is:

To deliver a fully operational, economically viable, carbon capture and storage business by mid 2020s. Initially capable of reliably and safely storing in excess of the 300kt/yr carbon dioxide currently emitted at St. Fergus gas terminal complex and designed to accommodate, both technically and commercially, additional future sources of CO_2 from Scotland and elsewhere in the UK & North Sea in excess of 5MtCO_2/yr.

With technical and commercial progress, the Acorn CCS project is well placed to establish the anchor CO_2 transport and storage solution for the Scottish industrial cluster as well as a material carbon capture facility. It could be the UK's first-mover CCS project and provide a key element in the wider decarbonisation of the UK and other countries around the North Sea.

The Acorn CCS project is entering the Define phase having completed the Concept Select phase. During the Concept Select phase, technical options have been evaluated and, where possible, a leading design concept has been selected in preparation for further engineering in the Define phase. The project has been developed on a standalone basis, although consideration (on a minimum regret basis) has been given where appropriate to the anticipated future build-out of the Acorn Project, including accommodating CO_2 volumes from the Acorn Hydrogen Project, also led by PBDE and due onstream after Acorn CCS start-up, and potential CO_2 onshore transportation from central Scotland and ship import via Peterhead.

It is proposed that the Acorn CCS project would gather emissions from the Shell Esso Gas and Liquids (SEGAL) gas turbines and North Sea Midstream Partners (NSMP) Frigg UK Association (FUKA) site hot oil and glycol furnaces at the St. Fergus gas terminal complex. Flue gases would be delivered to a carbon capture plant (CCP) located on the FUKA North site where a liquid solvent technology would be used to extract the CO_2 from the flue gases. The product CO_2 would be transported to the FUKA South site where it would be conditioned to export specification.

CO_2 would then be transported offshore using existing infrastructure in the form of the currently redundant 20" Goldeneye pipeline to the injection well. The contents of this report detail the preliminary Operations and Maintenance Philosophy for the Acorn CCS project as described above.

The Acorn Parties are seeking to agree in principle an appropriate business model with the Government with firm commitment to follow in line with the Acorn Parties' intention to enter into binding contractual commitments following Final Investment Decision (FID).

A number of key areas for this document remain work in progress at the time of writing.

- The selection of carbon capture technology will be finalised through a procurement process early in the Define phase.
- The subsea control premise is not finalised. The preferred concept, namely an electro/hydraulic umbilical to a nearby platform, has been presented in this report. Alternative control methodologies also being progressed.
- The location of the central control room is currently being studied, with the decision expected within the coming month.
- The ultimate owners and operators of the plant will dictate elements of the operating and maintenance philosophy. As indicated above this is dependent on binding heads of terms.

This O&M Philosophy reflects the current understanding of the Acorn CCS project in the early Define phase and will be updated as the project progresses.

2.0 Introduction

2.1 Project Summary

Acorn CCS is a phased carbon capture and storage (CCS) development project in the north-east of Scotland as shown in Figure 2-1. Acorn CCS is being designed to securely store captured CO_2 in the Acorn CO_2 Storage Site licenced area, as defined by an Oil and Gas Authority (OGA) Licence Agreement [1] and a Crown Estate Scotland (CES) Lease.

It is proposed that St Fergus gas terminal complex, located 55km north of Aberdeen, will be the onshore focus for Acorn CCS and that an existing, redundant, offshore gas pipeline will be re-purposed for transporting CO_2 to the Acorn CO_2 Storage Site licenced area.

This project will be led by PBDE with support from industry partners. The project is being partially funded by the EU as a Project of Common Interest (PCI) and partially by the UK Government, via the Department of Business, Energy and Industrial Strategy (BEIS) as part of the CCUS Innovation Fund.

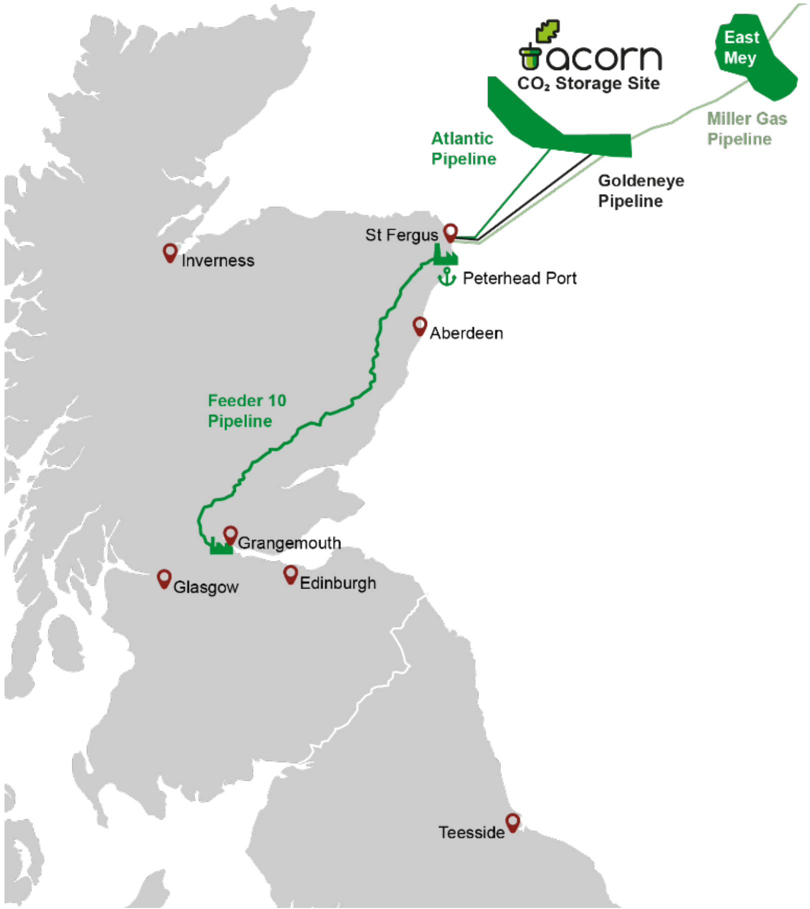

Figure 2-1: Acorn CCS Project map

As shown in Figure 2-2 the Phase 1 elements of the Acorn CCS project include:

- Flue gas collection from existing St Fergus gas terminal complex industrial emitters and transport of the flue gases to the CO_2 capture plant. The source of the flue gas will be gas fired compressor turbines on the Shell-Esso Gas and Liquids (SEGAL) plant, operated by Shell, and gas fired furnaces on the North Sea Midstream Partners (NSMP) Frigg UK Association (FUKA) plant, operated by PX Limited.
- Pre-conditioning of flue gas to remove SOx/NOx prior to entering the CO_2 capture plant (if required).
- CO_2 capture plant using a liquid solvent.
- Transport of the CO_2 from the CO_2 capture plant to the low pressure (LP) compression plant, conditioning of the CO_2 to remove oxygen and water, high pressure (HP) compression and cooling to meet the pipeline specification.
- Onshore tie-in to the offshore pipeline (including pigging tie-ins/facilities).
- Offshore infrastructure, including the re-use of the existing 20” Goldeneye pipeline and connection to one or more wells.
- Drilling and completion of one CO_2 injection well, capable of injecting, as a minimum, the Phase 1 volumes of CO_2 (300ktCO_2/yr), complete with the subsea tree(s).
- Subsurface work for the Acorn South CO_2 Storage Site and scoping work for the build-out.
- Well control.

The scope of the Acorn CCS project study also includes:

- Onshore health, safety and environment (HS&E) aspects to deliver a consentable, compliant design for Acorn Phase 1.
- Offshore HS&E aspects to deliver a consentable, compliant design for the Acorn South development and well control infrastructure (umbilical).

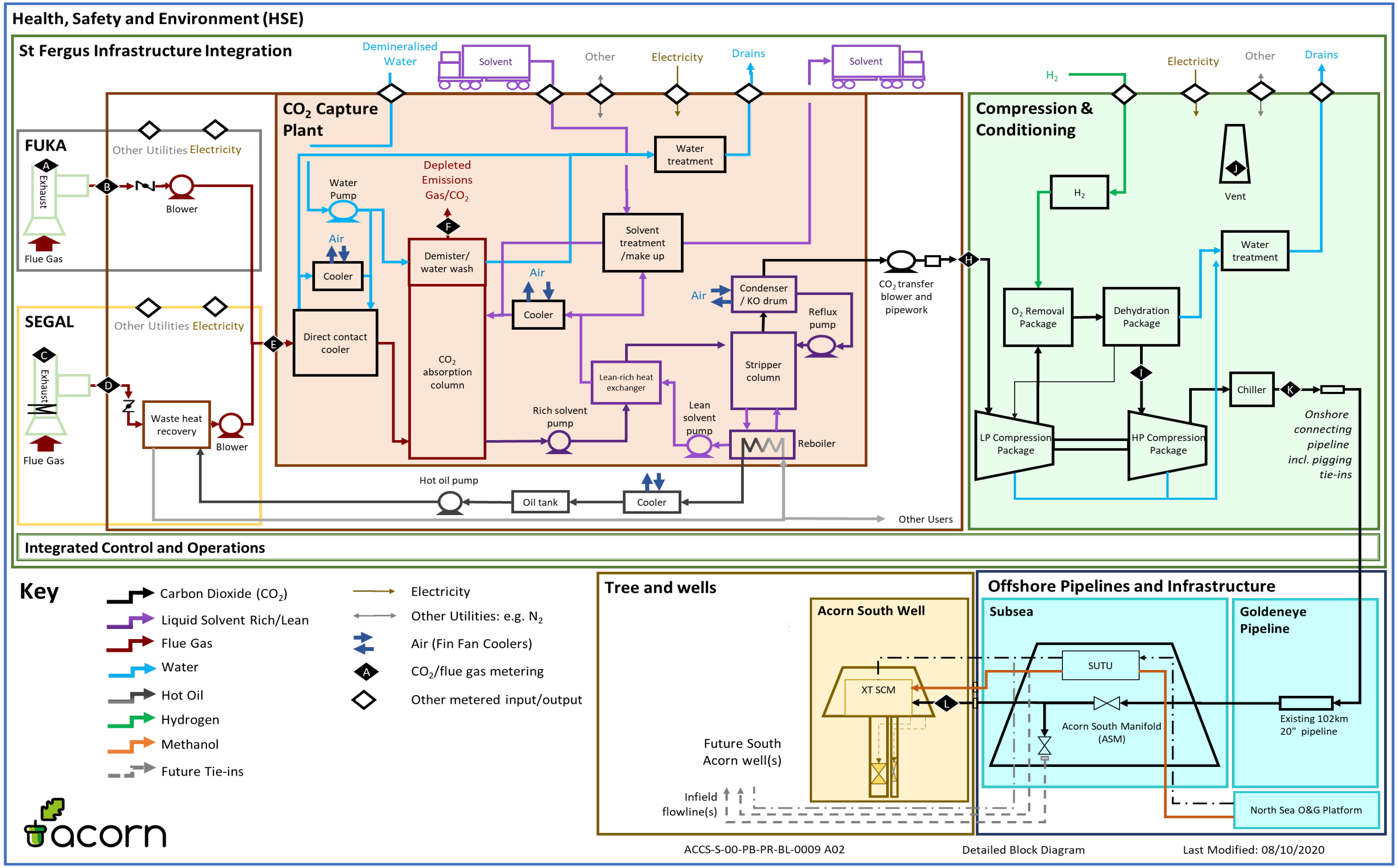

Figure 2-2: Preliminary Acorn CCS Phase 1 block diagram

Once the Phase 1 infrastructure has been established, Acorn CCS project could then be built-out via a number of potential Phase 2 options. These Phase 2 build-out options could include:

- Carbon capture from a new hydrogen plant (reforming natural gas) at St Fergus known as Acorn Hydrogen and onwards transport of the CO_2 to the Acorn CO_2 Storage Site licenced area
- Re-purposing of the National Grid Gas (NGG) Feeder 10 pipeline and infrastructure to transport CO_2 from the industrial centres around Grangemouth to St Fergus and onwards to the Acorn CO_2 Storage Site licenced area
- Re-using the existing Peterhead Port infrastructure (where feasible) and installation of new infrastructure to support import of CO_2 to the St Fergus Acorn facility and onwards transport to the Acorn CO_2 Storage Site licenced area
- Using the Peterhead shipping infrastructure to support the export of CO_2
- Drilling and completion of an additional well or wells capable of injecting, nominally 1.5–2.0MtCO_2/yr per well within Acorn South
- Offshore infrastructure, including new in-field flowline to one or more Acorn South well(s)
- Drilling and completion of further wells capable of injecting, nominally 1.5–2.0MtCO_2/yr each, at Acorn Central. The areas that represent Acorn South and Acorn Central are shown in Figure 2-3.
- Offshore infrastructure, including the re-purposing of the existing Atlantic pipeline, new in-field pipelines and manifold capable of expansion to further wells at Acorn Central
- An international interconnection utilising the Miller Gas System pipeline

Development of the offshore infrastructure and drilling and completion of additional wells would be as and when needed (subject to looking at efficiencies of campaign mobilisation/demobilisation costs and weather windows) to match the timing of new sources of CO_2 becoming available.

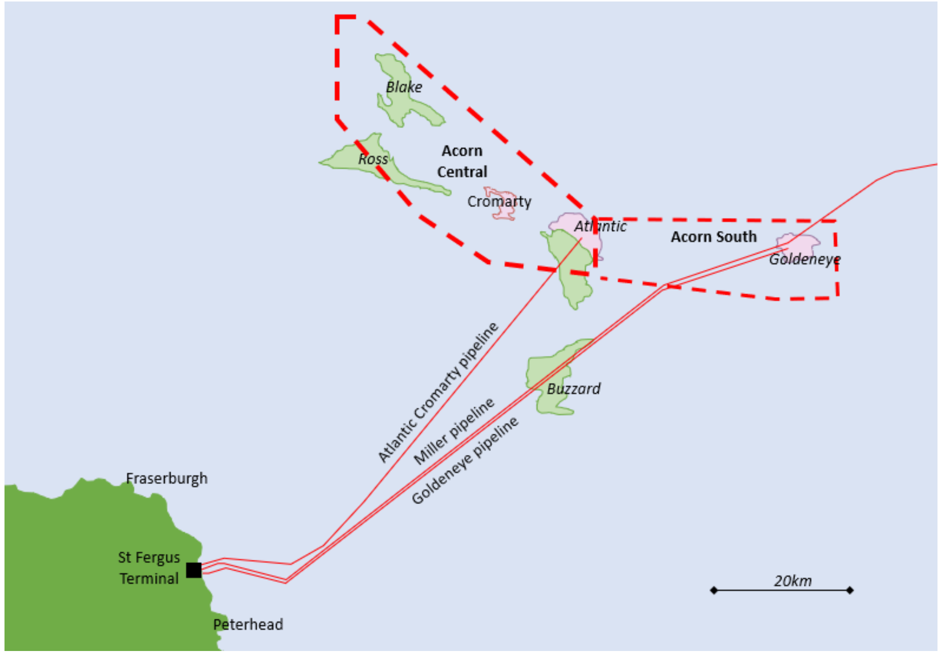

Figure 2-3: Acorn Central and Acorn South map

2.2 Commercial Framework

As indicated in section 1.0, the commercial architecture to support the agreements required to execute the Acorn CCS project is under development. The main elements are likely to be (Figure 2-4):

- CO_2 emitters (existing St Fergus operating entities – initially SEGAL and FUKA)
- St. Fergus Host sites (as above)
- Offshore Host
- “Acorn Capture Company (CapCo)” (extraction of CO_2 from Emitters’ waste flue gas or process gas streams from the emitters).
- “Acorn Transport and Storage Company (T&SCo)” (compression, conditioning and metering of purified CO_2, transport offshore and permanent storage in the Acorn geological storage site). HMG (revenue funding support and potential capital grants, potentially to both CapCo and T&SCo)
- An economic Regulator for the T&SCo
- Crown Estate Scotland (CO_2 Pipeline corridor and Storage pore-space lease – lease option existing)
- Oil and Gas Authority (CO_2 Storage licence – existing, CO_2 Storage permit – not yet obtained)

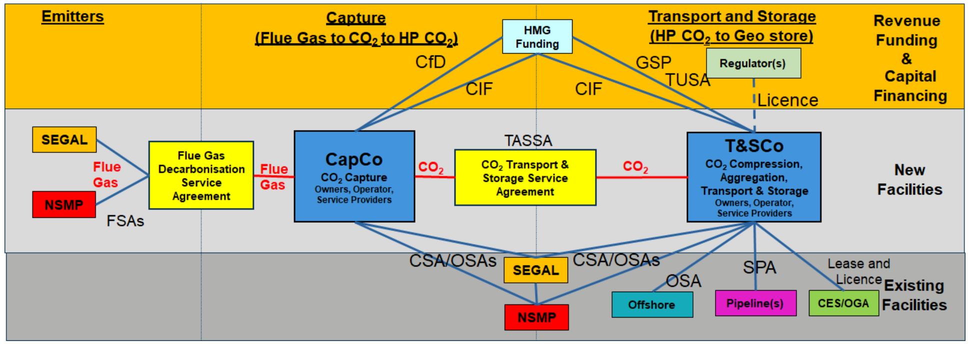

Figure 2-4: Preliminary commercial architecture (Decarbonisation Service Company Model)

(CfD = contract for difference, FSA = flue gas decarbonisation service agreement, GFA = grant funding agreement, OSA = operations service agreement, SPA = sales and purchase agreement, TASSA = transport and storage service agreement, TUSA = transport utilisation support agreement)

Ownership and operatorship of the CapCo and Acorn T&SCo are not yet defined.

2.3 Joint Venture

The Acorn Parties are currently signatories to a study agreement (Acorn Technical Development Study Agreement). The parties have also signed a MOU that provides the first step in the development of joint venture (JV) or shareholder agreements (contractual or incorporated JVs) in relation to ownership of the Acorn CCS project commercial entities (CapCo and T&SCo, or similar or combined entities). The development of these agreements will be progressed through the next phase of the project.

3.0 Scope

3.1 Purpose of Report

This Operation & Maintenance (O&M) Philosophy is intended to describe the operational and maintenance requirements to be applied to the design and to set out the preliminary philosophy for operations and maintenance of the Acorn CCS project facilities based on the current understanding of the project in the early Define phase.

The O&M Philosophy highlights the importance of HS&E and, given the shared facilities and close proximity to the existing Control of Major Accident Hazards Regulations (COMAH) and critical national infrastructure at the St Fergus gas complex, the requirement for close collaboration between FUKA and SEGAL and both CapCo and T&SCo.

Several O&M strategies are outlined within this philosophy, but their implementation will depend on the outcome of commercial discussions. This is highlighted within the document.

3.2 Operations and Maintenance Objectives

PBDEs objectives are to maximise CO_2 capture and storage, economically and with high environmental and safety standards and performance. This shall be achieved by defining operations and maintenance objectives which:

- Drive high HS&E standards and compliance to legislation.
- Manage workers risks to “As Low as Reasonably Practicable” (ALARP). This includes minimising risks from transport, major accidents and occupational hazards.
- Ensure capture of emissions at SEGAL and FUKA to meet contractual obligations.
- Ensure captured CO_2 is of sufficient composition and condition to meet the T&SCo offshore transport system obligations.
- Ensure transportation, injection, and storage of CO_2 to meet contractual obligations.
- Ensure containment of CO_2 within the reservoir.
- Operate both the CapCo and T&SCo facilities in the most cost-effective manner.
- Maximise the reduction of net greenhouse gas (GHG) emissions and ensure minimum environmental impact during all operations and maintenance.
- Safeguard the technical integrity of all infrastructure owned and operated.
- Respect the communities closest to the project.

3.2.1 Acorn Phase 2 Build-out

During subsequent phases of the Acorn CCS project, additional CO_2 volumes will be transported via the Goldeneye pipeline to the Acorn CO_2 Storage Site for injection and secure storage. The Acorn Phase 2 O&M strategies are not within the scope of this document.

3.3 Further Work

This O&M Philosophy reflects the current understanding of the project in the early Define phase and will be updated during the Define phase.

A number of assumptions have been made:

- Until ownership and operatorship of CapCo and T&SCo has been defined, industry standards and commonly adopted onshore and offshore operating and maintenance procedures have been adopted. Alignment with owners and operators operating and maintenance procedures will be assessed and adopted where and when reasonable and appropriate to do so.
- The required cooperation to address communication and integration requirements when operating in proximity with SEGAL and FUKA will be addressed in the commercial agreements between the parties.

4.0 Acorn Facilities Overview

4.1 Location

The proposed capture plant will be located in a vacant plot on the North of the FUKA site adjacent to the SEGAL site boundary (left hand side in Figure 4-1). Exact positioning of the capture plant is to be confirmed.

The compression and conditioning (C&C) plant is split from the capture plant and is located at the South of the FUKA site, adjacent to the decommissioned Miller reception facilities (right hand side in Figure 4-1).

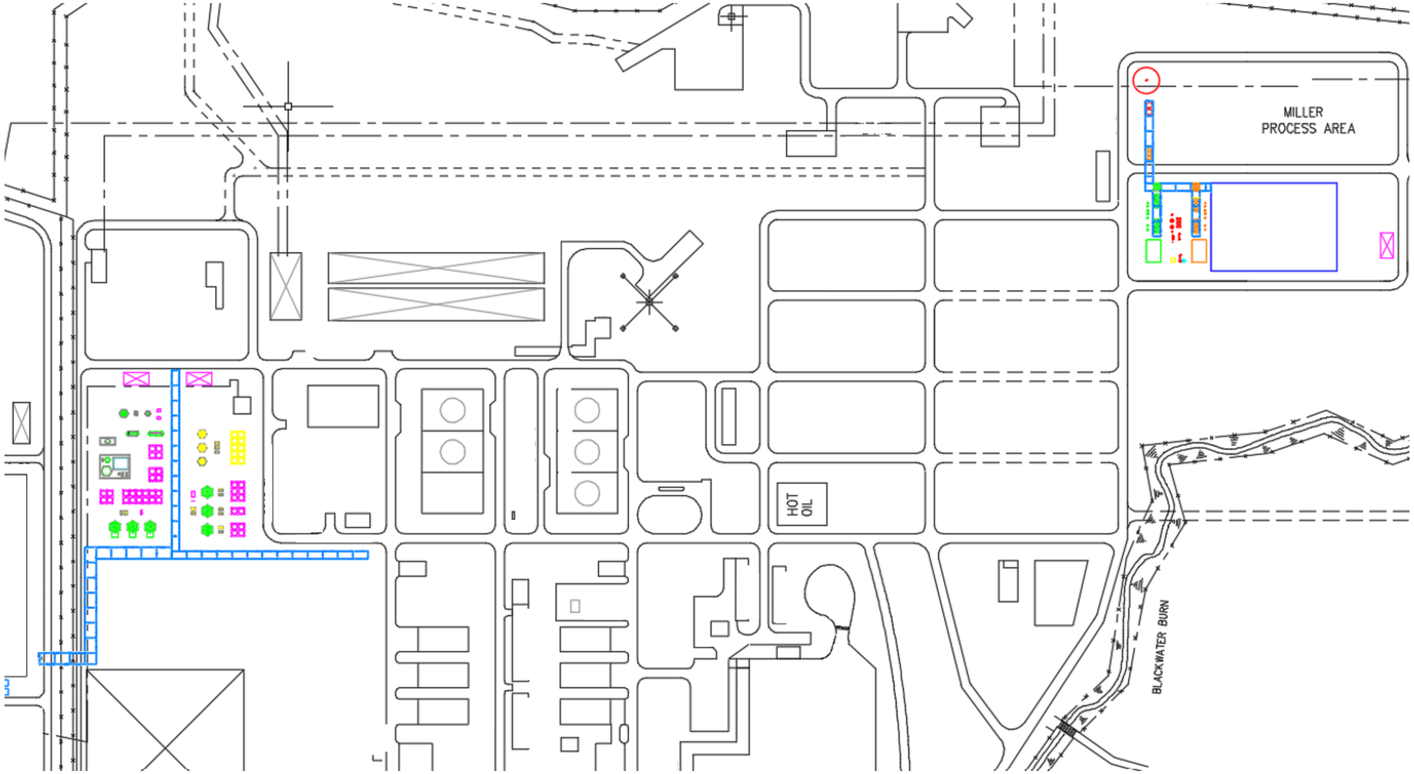

Figure 4-1: Acorn CCS Project layout at FUKA

4.2 Capture Company (CapCo) Facilities Overview

The Acorn CCS facilities at St Fergus are summarised in the block flow diagram shown in Figure 4-2 (Figure 2-2 for the key). Flue gases containing CO_2 are gathered from the respective source equipment at the SEGAL and FUKA sites via a ducting system. This combines the flue gases into a single stream which enters the Carbon Capture Plant (CCP). Prior to entering the carbon capture plant, waste heat is recovered from the SEGAL gas turbine (GT) flue gases via waste heat recovery units (WHRU) to a hot oil system. This heat is used throughout the carbon capture and conditioning plants where required, predominantly for regeneration of the capture plant solvent.

In the CCP, the combined flue gas stream is first cooled in a direct contact cooler (DCC). The cooled gas stream is then fed into the bottom of an amine solvent absorption column. The liquid solvent enters from the top of the column contacting the rising flue gas across packing in counter-current fashion. The amine reacts with the CO_2 and the rich solvent leaves from bottom of the column. The CO_2 depleted flue gas exits the top of the column via a water wash section, which removes volatile solvent and degradation products.

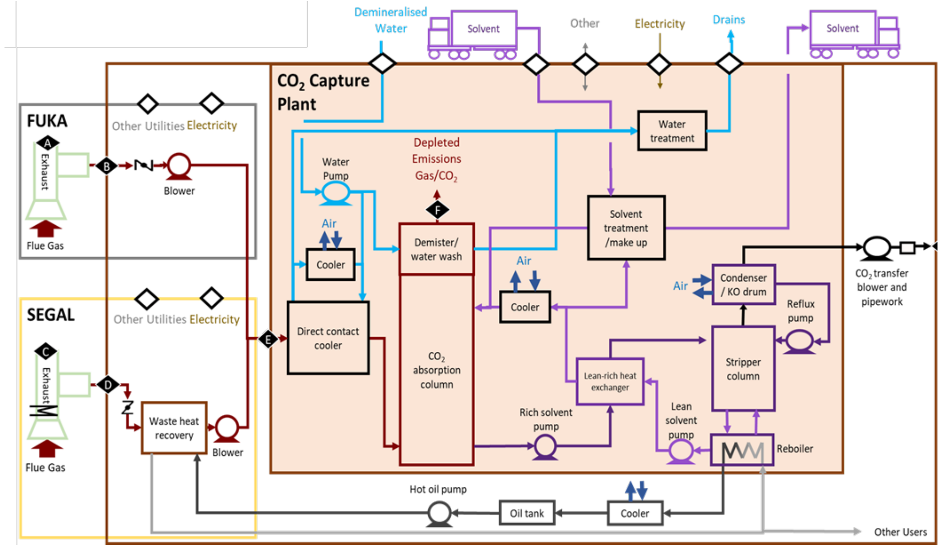

Figure 4-2: CapCo facilities

From the absorption column, the rich solvent is fed to a stripper column where it is thermally regenerated, and a concentrated CO_2 stream is produced. A reboiler provides heat to the solvent from the hot oil system. Hot regenerated solvent is used to pre-heat incoming rich solvent in the lean-rich heat exchanger, it is then further cooled and recycled to the absorption column. CO_2 produced in the stripper column exits via a reflux condenser, which condenses a proportion of the entrained water which is returned to the stripper column.

The CO_2 will then be conveyed to the T&SCo C&C plant via a gas phase pipeline using a booster fan. Before it leaves the carbon capture plant, metering will be used to verify custody transfer of the CO_2 between the CapCo and T&SCo plants.

4.2.1 Emission Sources

4.2.1.1 SEGAL gas turbines

The main emission sources on SEGAL are the two GTs which drive export gas compression. The GT exhausts stacks are shown in Figure 4-3. The GTs operate continuously in a 1x100% mode of operation for each of the two process trains at SEGAL.

Figure 4-3: SEGAL GT exhaust stacks (Image: Shell)

In the current plant configuration, flue gas from each GT leaves to atmosphere via one of two exhaust stacks shown in Figure 4-3. One of the stacks is fitted with a waste heat recovery unit (WHRU) whereas the second provides a bypass option. The WHRU units are connected to an existing hot oil system, although there is currently no continuous demand on site for the heat.

For the Acorn CCS project, a new hot oil heating system will be installed to service the needs of the new plant. Tie-ins shall be made to the exhaust stack downstream of the existing WHRU units. The existing WHRUs shall either be modified, replaced or left in situ with a new WHRU installed within the downstream ductwork. From the exhaust tie-in, a large diameter duct (≈$3m^2$) shall be installed to transfer the flue gas to the capture plant. One booster fan shall be installed for each GT.

4.2.1.2 FUKA (NSMP) hot oil furnaces

Two furnaces (Figure 4-4) provide heat for the hot system used by the FUKA Phase 3 plant. Both furnaces run continuously during normal operation, in a duty/duty mode of operation. The flue gases exit to atmosphere via dedicated exhaust stacks, after providing preheating to the hot oil inlet.

Figure 4-4: FUKA (NSMP) gas fired hot oil furnaces (Image: PX Group)

No waste heat recovery from the FUKA (NSMP) hot oil furnaces will be employed for the Acorn CCS project. As with the SEGAL GTs, tie-ins will be to the existing exhaust stacks. Again, separate booster fans will be employed for each unit, although the flue gases will be combined into a common length of ducting before routing to the capture plant. The hot oil furnaces are the furthest emission sources from the capture plant and will require significant ducting length, albeit of much smaller diameter than for the SEGAL GTs.

4.2.1.3 FUKA (Gassled) glycol furnaces

Two furnaces regenerate glycol for use on the FUKA Phase 2 plant. The furnaces operate in either a duty/duty or duty/standby mode of operation, depending on the heat demand upon the plant. The glycol furnaces exhausts are shown in Figure 4-5.

Figure 4-5: FUKA gas fired glycol furnace exhaust stacks (Image: PX Group)

Tie-in to the existing exhaust stacks will be required. Separate booster fans will be employed before the two flue gas streams are combined into a single duct before routing to the capture plant.

The two combined flue gas ducts from FUKA hot oil and glycol furnaces will be combined again into a single common duct for the final portion of the route to the CCP.

4.3 T&SCo Facilities

4.3.1 Onshore Overview

Water saturated CO_2 then enters the C&C plant at FUKA South, where it undergoes further purification and is brought to export conditions. Two levels of compression are employed, low and high pressure (LP & HP), both using integrally geared compressor technology. For the LP compression, 5 stages are anticipated, bringing the CO_2 to around 30barg. Interstage coolers maintain the temperature at required levels and knock-out vessels remove any condensing water as its solubility decreases.

Following the LP compression, oxygen is removed via a catalytic oxidation (CATOX) reactor to meet the export specification of 20ppmv. Here, hydrogen is fed into the CO_2 stream which then reacts any dissolved oxygen across a packed bed vessel. Afterwards the CO_2 is dehydrated in tri-ethylene glycol (TEG) absorption unit. A 50ppmv moisture level is specified to allow carbon steel equipment to be employed downstream and prevent corrosion of the Goldeneye pipeline. An enhanced TEG absorption process is required, which employs a gas stripping column in addition to the conventional absorber and regeneration columns.

After conditioning, the CO_2 is compressed to a normal export pressure of 90barg in the HP compression section. Two stages are anticipated to be required. To prevent running ductile fracture of the offshore Goldeneye pipeline, the compressed CO_2 must be cooled to 25°C to reduce its saturation pressure. To achieve this temperature, fin-fan coolers will be used, except for periods of warmer weather when a refrigeration package is required.

An onshore export pipeline connects the compressor train to the existing Goldeneye pipeline, where the CO_2 is transported to the Acorn CO_2 Storage Site for permanent sequestration.

4.3.2 Offshore Overview

The 102km, 20" carbon steel Goldeneye pipeline was previously used to transport natural gas condensate from the Goldeneye platform to the SEGAL site at St Fergus. It is expected that the onshore CO_2 export pipeline will tie-in at the existing repurposed pig launcher-receiver, located within the SEGAL site.

A new manifold will be deployed at the offshore terminus of the Goldeneye pipeline, allowing connection to an initial and future CO_2 injection wells. For Acorn CCS Phase 1, a single CO_2 injector, located 100-150 metres from the offshore end of the 20" pipeline, will be completed with a dual tubing string to provide high turndown capability.

This well will also be sized to enable injection of CO_2 volumes produced by the Acorn Hydrogen project. A deviated trajectory will be used alongside narrow tubing to provide a frictional pressure drop and prevent fracturing of the formation. A hydraulic subsurface safety valve (SSSV) will be provided for each tubing string.

A vertical X-mas tree will be used to control the flow of CO_2 into the tubing strings. Electrical and hydraulic power will be provided to the well through an umbilical, with the umbilical also containing fibre optic bundles to enable communication with tree valves and instrumentation. The leading concept is for the control umbilical to be tied back a nearby platform. Secure wireless communication link between the platform and shore will allow the well to be controlled from the Acorn control room.

Methanol, for downhole hydrate inhibition, will be provided to the well either via the existing 4" service line which runs parallel to the Goldeneye pipeline or within umbilical cores from the platform, depending on the concept selected.

5.0 Operations and Maintenance Teams and Infrastructure

5.1 Organisation Model

The Acorn CapCo and onshore T&SCo plants will be located within the operating boundaries of the FUKA site, with tie-ins to the existing FUKA plant across two different and separate areas of plant. There will be shared services and resources such as utilities, fire water, access and security, etc.

In addition, the Acorn CCS project will tie-in to and gather emissions from the GTs from the neighbouring SEGAL site. Plant on the SEGAL site will be dependent on shared services and resources at SEGAL such as utilities, fire water, access and separate security. This brings an added level of complexity.

This arrangement requires very careful consideration and planning to address day-to-day issues as well as the required collaboration between Acorn, SEGAL and NSMP/PX for dealing with the wider aspects of planning for escalating events such as a major CO_2 gas release, fire or explosion.

Aspects to be fully discussed and agreed as the Acorn CCS project matures towards Execute will include:

- Site emergency response plans and leadership
- Provision of emergency response team
- Daily event / work communication
- Permit to work synergies
- Site security and gate access
- Interlocks
- Control systems interfaces.

5.2 Operations and Support Team

The operations and support team structure will be developed through the Define and Execute phases of the project, with the staffing arrangements for the operation, maintenance, management and support services dependant on the Acorn CCS project ownership and operational commercial model adopted for both CapCo and T&SCo. The ultimate staffing levels may also be modified as a result of operational experience and build-out requirements, both in terms of additional resources and potential optimisation of personnel resulting from integration with build-out phases.

The staffing, recruitment and training of the operations and maintenance organisation shall be designed to ensure a safe, reliable operation.

5.2.1 Operations

A combined CapCo and T&SCo onsite operations team organogram shown in Figure 5-1 will be revised during Define. A total of 45 full time equivalent positions have been estimated, including provision for day/night shift.

The operations supervisor will be responsible for site HS&E activities. They will be supported by an Acorn CCS project asset HS&E team.

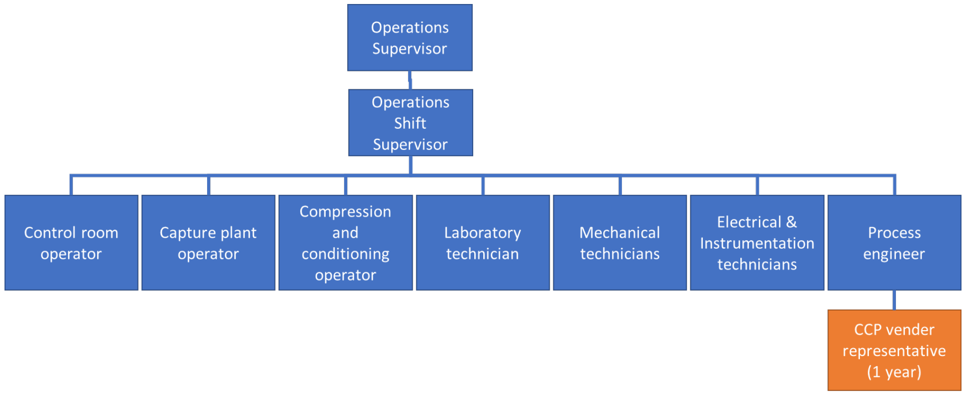

Figure 5-1: Operations team organogram

5.2.2 Maintenance Team

The core maintenance team requirement and resourcing will be developed based on the expected maintenance hours/load of the installed equipment.

Specialised or contract maintenance personnel will be required for non-routine and any major maintenance activity (e.g. Turnarounds, campaign maintenance etc.). Acorn CCS project turnarounds will be coordinated to align with SEGAL and/or FUKA shutdown periods.

Close coordination will be required to ensure the impact of maintenance on equipment on SEGAL and FUKA is understood and managed with respect to the Acorn CCS plant.

5.2.3 Support Team

The Acorn CCS project operations support team is anticipated to consist of a number of disciplines and supporting functions as shown in Figure 5-2. A total of 23 full time equivalent positions have been estimated.

This organogram shows only key functions and should not be considered fully comprehensive.

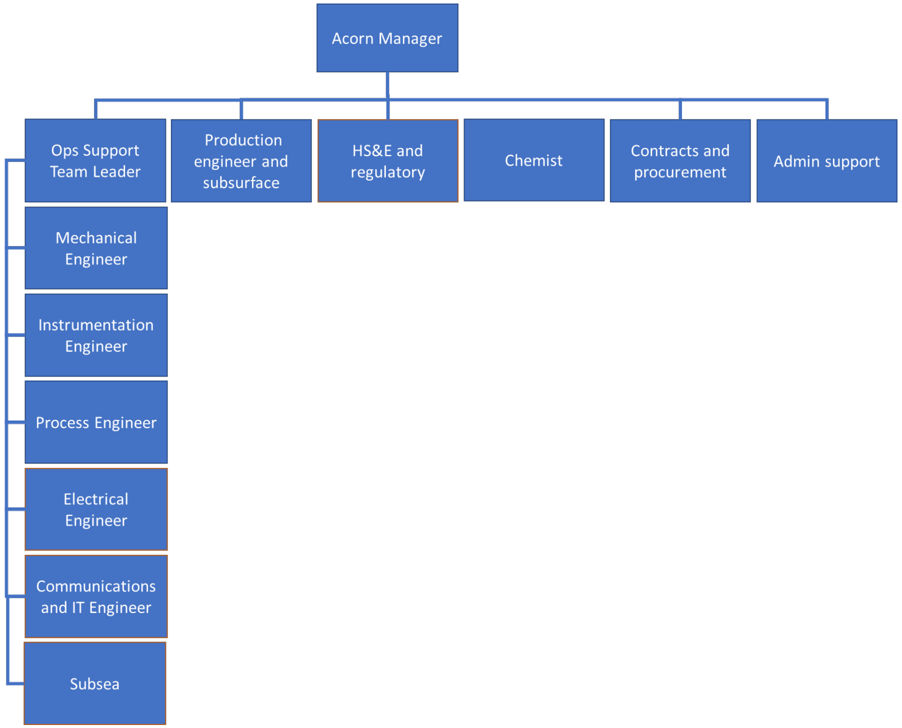

Figure 5-2: Acorn operations support team organogram

5.2.4 Competency and Training

The Acorn CCS project will draw upon the existing experience from the Acorn partners and the site operators and will aim to gather and implement learning/experience specific to CO_2 and CCS operations from similar projects.

The project will develop a comprehensive competency and training framework in Execute.

Consideration will be given to developing a dynamic simulator for design verification/testing and for training of engineering and operational staff. It will also be used to test start-up procedures.

5.3 Control and Support Infrastructure

5.3.1 Control Room Location

The control room will be designed to operate the Acorn CCS plant safety whilst maximising uptime to capture and securely store CO_2. The control room will operate the CCP, C&C, export pipeline pressure control and subsea well.

Initial screening of the control room location has identified two possible locations: new build close to the existing FUKA control room and a shared control room with FUKA. Both solutions ensure that occupied buildings are away from the hazards presented by both the existing gas facilities and the new Acorn CCS facilities.

The Acorn CCS control room will require strong communication links with both the SEGAL and FUKA control rooms.

5.3.2 Permit to Work Office

A combined FUKA/Acorn Permit to Work office may be put in place, depending on the Acorn operational commercial model adopted for CapCo and T&SCo.

5.3.3 Site Support Infrastructure

Support infrastructure at FUKA such as offices, maintenance workshops, stores and welfare will be required. The make-up of these facilities will depend on the Acorn operational commercial model adopted for both CapCo and T&SCo.

5.3.4 Emergency Response

Emergency response on the FUKA site is discussed in section 8.4. Provision of any required facilities will depend on the Acorn operational commercial model adopted.

No separate Acorn emergency response functionality is expected to be required on the SEGAL site, as all Acorn equipment within the SEGAL site is expected to be operated by SEGAL.

5.4 Logistics

5.4.1.1 T&SCo offshore

Facilities to support the offshore infrastructure will include onshore warehouse facilities to store spares (see Section 7.3.4). This may be a sub-contracted service using a shared warehouse or potentially through a subsea controls life of field service contract. In the latter case the supplier of the subsea controls equipment would be contracted to maintain spares in a ready condition.

5.4.1.2 Wells

Facilities to support wells maintenance may include onshore warehouse facilities to store workover equipment, or similar. This may be a sub-contracted service using a shared warehouse.

5.5 Information Management

Information Management refers to the control, retention and delivery of data during project execution through to commissioning, start-up and final operations.

During all phases of the Acorn project – Define, Execute and Operate - a controlled document management procedure shall be implemented, to ensure that key information is retained in an organised structure, available for handover to parties responsible for delivery of each project phase.

During Define, PBDE, as Lead Developer, shall be responsible for the controlled management of documentation. The software system selected for document control during Define phase is Microsoft SharePoint.

The software utilised for subsequent phases of the project shall depend on the entity which is responsible for delivery of that phase. All contractors working on the Acorn project shall be expected to utilise a controlled document management procedure, with an agreed process for handover of information at the end of their scope.

During the Operate Phase of the project, certain safety critical documentation shall be retained in hardcopy within the Acorn Central Control Room (CCR). The full list of documentation shall be developed during later phases of the Acorn project however, examples of safety critical documentation include:

- Operating manuals and procedures
- Process and Instrumentation Diagrams (P&IDs)
- Cause and Effect Diagrams (C&Es)
- Electrical Single Line Drawings (SLDs)
- Alarm and trip schedules

5.6 IT Infrastructure and Telecommunications

5.6.1 Software Applications

Software applications shall be based on common systems suitable for the level and functionality required. For the Acorn CapCo and T&SCo equipment located within the FUKA site, consideration will be given to adopting the software systems used on the FUKA/PX site. All Acorn CCS project equipment within the SEGAL site will be incorporated into the existing SEGAL system. Close coordination of maintenance requirements outside of the Acorn CCS system will need to be managed.

The typical applications required will be:

- Control of work system e.g. Engica Q4
- Information management system or plant historian e.g. PI
- Computerised maintenance management system (CMMS) e.g. Engica Q4, SAP, Maximo
- Operations log

5.7 Communications Infrastructure

5.7.1.1 Telephones

The Acorn CCS project control room will require telephones for both on-site and off-site communications. This is likely to be a separate telephone exchange and incoming line for commercial reasons, although it could be an extension of the existing FUKA site telephone system.

The panel operators will need to be able to quickly communicate with the FUKA and SEGAL control rooms for emergency response situations and operational reasons. This may require dedicated lines run between the control rooms rather than connection through exchanges.

5.7.1.2 Radios

It is anticipated that the Acorn CCS plants will require radio coverage for operations, maintenance and emergency response purposes. This will require a radio base station in the Acorn CCS control room and may require additional transmitters around site to provide coverage for the Acorn units. The Acorn frequencies will be unique and separate to existing FUKA and SEGAL frequencies.

Radio handsets will need to suitable for hazardous areas (i.e. explosive atmospheres) to allow them to be carried around the St Fergus site.

5.7.1.3 Offshore Communications

The Acorn South CO_2 injection well will be controlled directly from the Acorn control room with a master control system (MCS) being located on the nearby platform. The operator has presented options for Acorn communications between the St. Fergus control room and the offshore MCS. These include a Line of Sight (LoS) link from Mormond Hill and use of the Tampnet offshore 4G network. Further work will be carried out to assess security, reliability and bandwidth across these options and determine if one, or both, are to be used.

In the event of loss of communication then a Remote Operator Workstation (ROWS) on the platform can be used to directly control the Acorn well(s). However, in normal operating mode this will perform a monitoring function only.

Radio communications will therefore be required between the Acorn onshore control room and the platform to allow coordination in the event of any offshore problems.

5.7.2 Cyber Security

A cyber security philosophy will be developed during Define phase to identify the physical, hardware, software and procedural requirements to protect the systems against external and internal vulnerabilities. This philosophy may take account of existing philosophies on both the FUKA and SEGAL sites and is likely to require each site’s key requirements due to the potential to impact on the SEGAL and FUKA/PX operations.

Minimum requirements are likely to include:

- Physical security for control and equipment rooms and network equipment panels
- Procedural requirements for system access
- Firewalls between control systems and business/corporate networks
- Secure backup and restore systems for configuration databases and controllers
- Security hardening of PC’s including locking down of USB and other access ports
- Network hardening (including locking of unused ports on switches and routers)

6.0 Operating Philosophy

The Acorn CCS project objective is to maximise CO_2 storage, economically and with exemplary safety standards and performance.

The process control philosophy shall be based on minimum operator or maintenance intervention and shall be self-regulating within acceptable operating bands. Operation such as start/stop and control of equipment will be through remote monitoring, remote control, and full automation using proven technology. The Acorn CCS project facilities on the FUKA site and offshore will be operated as a single plant, irrespective of the ownership of CapCo and T&SCo.

Alarms will indicate to the operator when conditions occur outwith the normal operating band and action is required to rectify the situation. The operating system shall include alarm management functionality including alarm prioritisation, alarm performance monitoring, and suppression (mode dependant, dynamic, and static).

Real time plant historian (e.g. PI) data shall be made available for plant surveillance, process performance monitoring, and troubleshooting by site supervisory staff, support staff and, where appropriate, specialist vendors. Control room and plant operators will be able to perform trending using the plant control system interface.

6.1 Operating Modes

The following section describes the different start-up and shutdown operating modes for the Acorn plant as set out in the Acorn CCS Control Philosophy document [2].

6.1.1 Normal Operation

During normal operation, the Acorn onshore facilities shall be in automatic mode of operation, necessitating minimal intervention from the control room operator. Automated control loops shall maintain the process conditions within an acceptable operating band, with alarms indicating to the operator when conditions occur out with the normal operating band and action is required to rectify the situation.

Manual (remote) control of the offshore wells shall be required to manage both the well and the subsea pipeline.

6.1.2 Start-Up

There are two main types of start-up: a cold start and a hot start; additional start-up types may be developed during Define. The following section provides an overview of each start-up type and key steps involved in a plant start-up. During Define, start-up steps shall be defined in greater detail.

6.1.2.1 Cold start-up

A cold start shall be required when the Acorn plant is depressurised, or when the Acorn plant has been offline for a significant duration of time, such that the process has cooled down to ambient temperature. Based on the CO_2 phase envelope, at ambient temperature and export pressure the Goldeneye pipeline will remain in liquid phase. If the pipeline pressure and temperature indicate that the pipeline is in two phases, the pipeline start-up procedure will be followed.

At a high level, the following steps shall be followed during a cold start-up:

- In order to commence with a cold start of the Acorn plant, it is assumed that one or more of the SEGAL GTs are online with the exhaust routed through the bypass exhaust stack. Once Acorn CCS plant is ready to receive flue gas, the Acorn CCR shall contact the SEGAL CCR to confirm that supply of flue gas from the GTs is available.
- Once confirmation has been received, the Acorn CCR shall bring the Acorn CCS plant hot oil circulation pumps online, with all hot oil routed initially via the hot oil trim cooler.
- Once the hot oil pumps are online, the Acorn CCR will confirm with the SEGAL CCR that they are ready to receive flue gas and request supply of flue gas from the GTs to begin. SEGAL to gradually re-route flue gas from GT bypass stack to Acorn, start flue gas blower and commence forward flow of flue gas to the Acorn capture plant. Interlocks will be in place to ensure that the flue gas cannot be passed forward unless the Acorn plant is ready.
- Flue gas to initially be vented via the vent on the CCP absorber column, with solvent loop offline.
- Whilst venting flue gas, hot oil system will gradually warm up to normal operating temperature.
- Once hot oil reaches required operating temperature, it will be routed to the solvent regeneration system.
- Start-up solvent regeneration system and feed forward solvent into the absorber column. Gradually ramp up solvent recirculation rate to normal operating rate.
- Feed CO_2 forward to the C&C plant and gradually pressurise the C&C system in a phased manner as per the compressor manufacturer guidance.
- Commence start-up of C&C system as per vendor operating procedures.
- Once plant and pipeline pressure has equalised, and the CO_2 is within the export specification. confirm with SEGAL and open pipeline emergency shutdown valve (ESDV) and commence export of CO_2 into the Goldeneye pipeline.
- Commence routing of other emissions sources to the Acorn capture plant (SEGAL GT and FUKA hot oil/glycol furnaces)
- Commence CO_2 injection well start-up as per well operating guidelines.

Depending on the duration of time to pressurise the C&C plant, it may be preferrable to feed forward additional flue gas to the capture plant earlier, in order to speed up pressurisation and minimise lost revenue for CapCo and T&SCo.

6.1.2.2 Hot Start-Up

A hot start shall be required following a short duration trip/outage of the Acorn plant, in which the plant remains pressurised and close to normal operating temperature. It is expected that there will be several hot start-up procedures, depending on the mode of operation/condition of Acorn CCS facilities prior to start-up. These procedures shall be developed during Define, in conjunction with the CCP vendor.

At a high level, the following steps shall be followed during a hot start-up:

- Upon confirmation from SEGAL that one or more GT is ready, if the hot oil pumps are not running, then Acorn hot oil circulation pumps shall be brought online, with all hot oil routed initially via the hot oil trim cooler.
- Once the plant is ready the Acorn CCR will request SEGAL to re-route flue gas from GT bypass stack to Acorn, start flue gas blower and commence forward flow of flue gas to the Acorn capture plant.
- Flue gas to initially be vented via the vent on the capture plant absorber column, with solvent loop offline.
- If required, allow hot oil system to gradually warm up to normal operating temperature.
- Once hot oil reaches required operating temperature, route to the solvent regeneration system.
- Start-up solvent regeneration system and feed forward solvent into the absorber column. Gradually ramp up solvent recirculation rate to normal operating rate.
- Feed CO_2 forward to the C&C plant and commence start-up of C&C system as per vendor operating procedures.
- Commence export of CO_2 into the Goldeneye pipeline.
- Commence routing of other emissions sources to the Acorn capture plant (SEGAL GT and FUKA hot oil/glycol furnaces).
- Commence CO_2 injection well start-up as per well operating guidelines.

6.1.3 Shutdown

Two types of shutdowns shall exist for the Acorn CCS plant – a planned and unplanned shutdown.

A planned shutdown shall be initiated intentionally by the Acorn CCR and will require communication with FUKA and SEGAL prior to initiation.

An unplanned shutdown shall be initiated automatically by either a trip from the Acorn Emergency Shutdown (ESD) or Fire and Gas (F&G) system, or indirectly via a SEGAL/FUKA unplanned shutdown. Additionally, a major ESD on the platform may initiate well shutdown. Alternatively, an unplanned shutdown could be initiated by manual intervention from either the Acorn control room or an emergency pushbutton in the field.

Different modes of shutdown shall exist for each section of plant.

In a CCP shutdown, the C&C plant shall be isolated from the CCP. The C&C plant will continue to operate in recycle and the well shall operate at a “minimum injection” rate. Operating the pipeline from 90 barg export pressure down to 75 barg export pressure is expected to take a minimum of 2 hours based on the Acorn CCS flow rates. This type of shutdown will only be enacted if the CCP outage is for a short duration.

In a C&C shutdown, the CCP plant will continue to operate but will vent flue gas or gaseous CO_2 via the absorber column. This type of shutdown will only be enacted if the C&C outage is for a short duration. If an extended duration outage is expected, then flue gas routing will be swapped such that emissions are vented via the bypass exhaust stack on each emission source.

In a well shutdown, the CCP and C&C plant will continue to produce CO_2, line packing the pipeline. Line packing from 90barg export pressure to 108barg export pressure is expected to take a minimum of 2 hours for Acorn CCS flow rates.

Depending on the reason and expected duration of any Acorn CCS plant outage, it may be necessary to continue circulation of the hot oil system via the trim cooler, such that the hot oil is cooled down to a lower temperature, ensuring that it does not present a temperature hazard to personnel. This shall be covered within operating procedures to be developed during the Execute phase of the project.

6.1.4 Well Operations

Due to Joule Thomson (JT) cooling across the offshore choke during both shut-ins and start-ups close monitoring and adherence to the start-up processes should be followed. A comprehensive set of well operating procedures are provided with the Acorn CCS "Well Operating Guidelines" [3] which includes management of low temperatures and potential hydrates.

6.2 Equipment Operating Philosophies

6.2.1 Gas Gathering Equipment Control Philosophy

The gas gathering system is defined as the ductwork and blowers which transfer flue gas from the SEGAL and FUKA emissions sources to the CCP. For the SEGAL emissions, the gas gathering system will also include provision of a waste heat recovery system, for recovery of waste heat for use within the Acorn CCS facilities.

Engineering work is currently ongoing to define the method by which flue gas emissions will be routed from SEGAL and FUKA to the CCP. Two options have been identified:

- Use of diverter dampers to route emissions between either ductwork to CCP or bypass exhaust stack.
- No installation of diverter dampers, instead relying on blowers to 'pull' emissions through to the CCP. Bypass exhaust stack open to atmosphere, enabling emission sources to float on atmospheric pressure.

The relative advantages/disadvantages of each option are currently under review, prior to selection of the preferred solution.

Engineering work is currently ongoing to define the waste heat recovery design for the SEGAL flue gas. Options under consideration include:

- Provision of a new standalone WHRU within the SEGAL gas gathering system, integrated with a new Acorn hot oil system on either the SEGAL or FUKA sites.
- Modification or replacement of existing WHRU on the SEGAL site, with integration between existing SEGAL hot oil system and the new Acorn hot oil system.

Although this decision is outstanding, the operating & control philosophy shall be that any new WHRU or hot oil system installed on the SEGAL site shall be controlled and shutdown from the existing SEGAL CCR.

6.2.1.1 Gas gathering operational interfaces

Control and shutdown of the blowers on the SEGAL site shall be carried out from the SEGAL CCR, through the existing SEGAL Distributed Control System (DCS) & ESD systems.

Control and shutdown of the blowers on the FUKA site shall be carried out from the FUKA CCR, through the existing FUKA DCS & ESD systems.

The control interface between the Acorn DCS and both the SEGAL and FUKA DCSs, shall be designed to maintain the pressure within the ductwork and capture plant to within the predefined operational limits. The blower speed will be adjusted using variable speed drive(s). The Acorn DCS shall monitor relevant process parameters, such as CCP inlet pressure and exhaust stack pressure. The DCS will then calculate a setpoint for the variable speed drive on each blower and the Acorn DCS shall send this setpoint to the SEGAL and FUKA DCSs, which will then adjust the variable speed drive accordingly for each blower, ensuring that the pressure remains within the acceptable operating band.

If the CCP inlet pressure exceeds the high-pressure switch, then the Acorn DCS will send an automatic intertrip to the SEGAL and FUKA DCSs, to reroute emissions via the bypass exhaust stack. Similarly, any shutdown action from the Acorn ESD system will send an intertrip to the SEGAL and FUKA ESD systems, rerouting emissions via the bypass exhaust stack and closing the route to Acorn CCP.

6.2.2 Capture Plant Control Philosophy

The capture plant will be controlled as per the operating and control philosophy to be developed by the CCP vendor during Define.

The DCS and ESD system specified by the CCP vendor shall be integrated into the overarching Acorn DCS and ESD.

6.2.3 C&C Control Philosophy

The C&C packages will be controlled as per the Original Equipment Manufacturer (OEM) guidance.

The Goldeneye pipeline shall be controlled on the basis of pressure by the well choke. A new pressure control valve (PCV) shall be installed immediately downstream of the Acorn export CO_2 metering, which shall control the backpressure on the onshore plant. During normal steady state operation, the PCV should sit 100% open, with the PCV only actuating during transient (start-up/shutdown) conditions.

Initial pressurisation of the Goldeneye pipeline will require one or more bypass lines from various stages of the compression system to the chiller and export composition analyser to ensure the CO_2 entering the pipeline remains within the specification.

The CCP and C&C plants shall be controlled from the same CCR, with both plants integrated into the Acorn DCS & ESD systems.

6.2.4 Goldeneye Pipeline Operating Philosophy

A technical note has been written which provides justification for the selected pressure operating range of the Goldeneye pipeline [4]. The pipeline shall operate in single (liquid) phase, both during operation and when the pipeline is shut in. The operating range of the Goldeneye pipeline is shown in Table 6-1.

Parameter	Value	Comment
Goldeneye Pipeline Design Pressure	132 barg	
Minimum Operating Export Pressure	75 barg	Based on the phase envelope of the CO_2 with the maximum contaminants, at a maximum temperature of 25°C and a margin of 10%.
Normal Operating Pressure	90 barg	
Maximum Operating Export Pressure	108 barg	Based on a static head at the lowest point in the pipeline, which is the ASM and a margin of 10%.
Maximum Design Export Pressure	120 barg	To account for increase in static head of 12barg over the length of the Goldeneye pipeline

Table 6-1: Goldeneye Pipeline Operating Pressure Regime

Due to the difference in elevation between the Goldeneye pipeline inlet at SEGAL and the outlet at Acorn South, at low flow rates there will be an increase in pressure over the length of the pipeline of approximately of 11 barg. This is the reverse of a conventional oil and gas project, in which there is normally a pressure loss between the offshore well and the onshore receiving terminal. This shall be made clear to operators both through documentation and training.

6.2.4.1 Goldeneye pipeline ESDV

When the Goldeneye pipeline was previously in operation, the pipeline and ESDV were controlled from the SEGAL CCR. The primary function of the ESDV is to act as an isolation valve between the onshore facilities and the Goldeneye pipeline inventory. Therefore, control and operation of the ESDV should reside with the entity responsible for operation of the onshore plant.

The SEGAL CCR may also be provided with the ability to independently close the Goldeneye pipeline ESDV and isolate the SEGAL site from the FUKA site. This will be accessed and agreed in Define.

During Define, the Goldeneye ESDV, along with other valves and instrumentation on the pipeline, shall be reviewed to confirm if they are suitable for re-use in dense phase CO_2 service.

6.2.4.2 Goldeneye pipeline packing

During normal operation, all CO_2 exported from the Acorn CCS onshore facilities shall be injected into the reservoir via the well. However, during certain scenarios, it will be necessary to 'pack' the Goldeneye pipeline. Such scenarios could include:

1. Outage/trip of CO_2 injection well
2. Outage of a single SEGAL GT(s), resulting in CO_2 export rate which is lower than the minimum turndown flowrate for the CO_2 injection well

It is advantageous for the Acorn CCS project to continue to capture and export CO_2 during these occasions. During Scenario 1, CO_2 will continue to be exported into the Goldeneye pipeline whilst the injection well is offline. This will gradually increase the pressure within the pipeline and will eventually result in a high-pressure shutdown. Assuming the CO_2 injection well remains unavailable, the onshore plant will need to take an outage. Pipeline packing can only be carried out for a limited duration (from 90 to 108 barg line pack modelled to take a minimum of 8 hours at low rates).

During Scenario 2, it will be possible to continue to inject into the well at the minimum design rate until the low-pressure operating point is reached. At this point, the CO_2 injection well can be shut-in and the pressure within the pipeline can be packed back to the maximum operating point. This cycling can be repeated, such that no outage of the onshore facilities is required.

However, frequently varying the Goldeneye pipeline pressure and operating the well in this manner is not preferred from a thermal-mechanical perspective. There may also be a risk of well formation damage if cycling is repeated too quickly or too often in a short period of time. This shall be checked during Define, to confirm that the proposed well cycling activity presents minimal risk of well and equipment damage and that the accumulated fatigue is acceptable.

The process of line packing will be important during the first year(s) of Acorn CCS project operation, when, if there is an outage of a single SEGAL GT, the export rate will fall below the minimum well turndown. Well cycling could improve the availability of the onshore Acorn CCS facilities. It should be noted that the heat from the SEGAL GTs is required to run the CCP plant and that FUKA emissions collection cannot run in isolation.

6.2.5 Well Control Operating Philosophy

A summary of the well control architecture is shown in Figure 6-1.

The diagram shows a dual completion well where each tubing string can be separately isolated and brought online individually or together using the subsea Christmas tree (XT) valves. A common choke is used to control both tubing strings. All valves are actuated hydraulically. Pressure and temperature monitoring of both the tree and downhole conditions are used to enable effective monitoring and control of the well. The “A” annulus pressure is monitored directly via a tapping into the annulus bore and downhole annulus pressure and temperature measurement. Each tubing string will have a hydraulically actuated SSSV which will act as a safety critical barrier in the very unlikely event of wellhead breach.

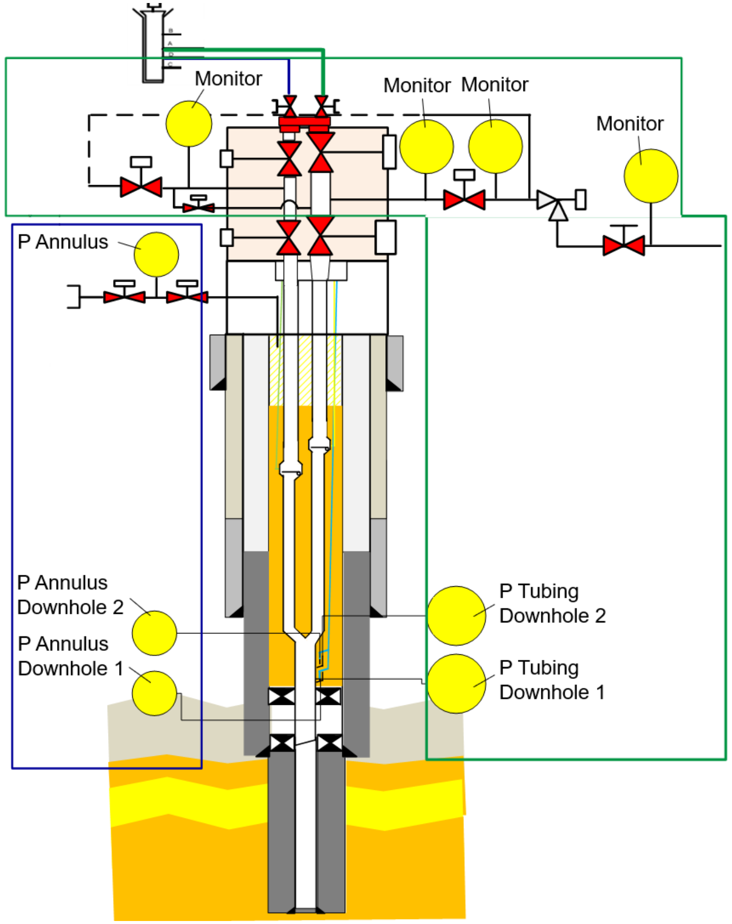

Figure 6-1: Well schematic

The CO_2 injection well shall be controlled via a subsea choke valve on the subsea XT. Manual adjustment of the choke valve position shall be completed remotely from the Acorn CCR. A subsea flowmeter will be installed either at the Acorn South Manifold (per XT) or on the subsea XT. The choke valve position is expected to be adjusted to achieve a balance between the desired flow rate, the desired tubing head pressure (THP) (and respective bottom hole pressure) and the pipeline pressure. This balance will vary with reservoir pressure and will be defined in well operating guidelines which will indicate whether one or two tubing strings should be open, what position the subsea choke should approach whilst monitoring the tubing head pressure and downhole pressures. The steady state operating position will be achieved when a stable tubing head pressure, flow rate and Goldeneye pipeline pressure are achieved and within their defined operating limits (Table 6-1).

Due to the 102km inventory of the Goldeneye pipeline, the pressure response to any change in choke position will be slow. This will need to be understood by the CCR when making changes to the choke position on the well. The pressure will vary over the 102km bathymetry of the pipeline, hence, pressure instrumentation installed at the onshore and offshore ends of the Goldeneye pipeline shall have different alarm/trip settings, to reflect this difference.

Subsequent wells which are drilled shall utilise similar flow measurement technology, to allow for allocation of CO_2 between different injection wells and different sections of the reservoir.

To ensure that CO_2 remains in liquid phase during steady state injection, the well THP downstream of the choke valve must exceed 50barg (see Pipeline Operation Technical Note [4]). The temperatures on the XT shall also be monitored to ensure that under steady state conditions it does not drop significantly below seabed freezing temperature or approach the bubble point of the CO_2.

Note: During transient conditions (especially for lower reservoir pressure) the well will cool down during both well shut-ins and well start-ups due to JT cooling effects. Cooling to about -10°C is anticipated which will not compromise the well's integrity.

The THP and temperatures (THT) shall be monitored continuously by the CCR. To prevent the THP or temperature from taking excursions beyond the set points the following shall be considered:

- A software interlock, preventing further opening of the choke valve until the pressure and temperature are within the defined set points (including start-up override).
- Procedural control, which states to the operator the maximum to which the choke valve can be opened, without exceeding the THP &/or THT set points.
- Alarms within the DCS, which indicate when conditions are out with normal operating values.
- Software/procedural limits to how quickly the choke can be opened.

The selected solutions shall be confirmed during Define, recognising the consequence to the well and reservoir if these THP and temperature limits were to be exceeded.

6.2.5.1 Well monitoring & integrity equipment

To facilitate effective well control in addition to ensuring both the well and reservoir are performing within the expectations of the "Measurement Monitoring and Verification (MMV) Plan" the following permanently installed monitoring equipment is planned to be installed:

- Dual redundant wellhead pressure (WHP) & wellhead temperature (WHT) (upstream choke).
- Dual redundant THP & THT (downstream of the choke).
- Two sets of dual downhole pressure and temperature gauges within tubing set 200ft apart (vertically).
- Dual downhole pressure and temperature gauges within "A" annulus.

Note: Distributed Temperature Sensors (DTS) and distributed Acoustic Sensors (DAS) using optical fibre strapped to the outside of the tubing are being considered (not in base case at present) to aid low temperature monitoring during JT cooling episodes, in addition to acoustic monitoring which will listen for any tubing/casing leaks.

In addition to the above monitoring equipment the integrity of the well is assured by the installation of SSSVs on each tubing string which are actuated closed in the event of an ESD signal and fail to the closed position on loss of hydraulic actuation fluid. Further details on well and reservoir monitoring in addition to well operations and associated well operations and intervention equipment is provided within the Acorn CCS project "Well Operating Guidelines" [3].

6.2.5.2 Offshore platform operational interfaces

Day to day control of the well will be from the Acorn CCS project control room at St. Fergus. Control and monitoring of the subsea wells will be achieved through:

- A link from the St. Fergus control room to offshore operator.
- Wireless links from shore to the platform (satellite, 4G and /or radio).
- Hardwired fibre-optic (FO) link from the platform to the ASM and onto individual wells via an umbilical.

A service agreement will be put in place between the Acorn T&SCo operator and offshore operator to cover maintenance of the Acorn subsea controls equipment on the platform. This will include monitoring, interfacing and arranging for equipment supplier technicians to visit the platform to carry out maintenance and repairs if required.

Although a ROW will be included on the platform for the Acorn subsea facilities this will only be used by operators in exceptional circumstances, such as loss of control signal from shore, and will primarily provide a monitoring function.

6.3 Instrumentation Systems

6.3.1 Process Automation and Control

The Acorn DCS shall be designed to carry out the control, monitoring, logging and reporting for the Acorn CCS project onshore and offshore facilities. The DCS will also provide the Human Machine Interface (HMI) and automatic control system for Acorn, whilst also acting as the HMI for the F&G, ESD, metering and offshore MCS.

Vendor packages such as the CCP, compressor package, conditioning packages and utilities may have their own package specific control systems or programmable logic controllers (PLCs) which shall interface with the overall Acorn DCS.

6.3.2 Emergency Shutdown System

The emergency shutdown system shall shutdown the plant, or subsections of the plant, upon confirmed process deviations outwith their permitted operating range, or confirmed fire and gas events. The operator interface to the ESD system shall be via the Acorn DCS, with the operator able to view the ESD parameters via the operator HMI console.

6.3.3 Fire and Gas System (F&G)

The fire and gas system shall provide an independent protective layer, which mitigates the consequences of a fire or gas release, being CO_2, hydrocarbon or another explosive mixture that could conceivably be released, by initiating an Acorn CCS plant shutdown upon detection of such an event. The fire and gas system shall be designed to monitor areas in which a fire or CO_2 release could occur, then take action to prevent escalation of an incident, whilst providing time for personnel to evacuate the area to a safe location.

6.3.4 Subsea and Well Control

The Acorn DCS shall communicate with the Acorn MCS, for control, shutdown and monitoring of subsea equipment and CO_2 injection wells. It is anticipated that the Acorn MCS shall be located on the nearby offshore platform, with data connections between the offshore MCS and the onshore Acorn MCS, which communicates with the DCS.

Potential means of communication and control between a St. Fergus control room and the platform are discussed in Section 5.7.1.3. Under normal operations, well control will be from onshore. However, in the event of loss of communication from shore then control of subsea wells could be carried out from the platform.

The Acorn CCS project systems on the platform will have inputs / outputs to the existing control system. However, it is expected that only high level ESD events on the platform would impact Acorn CCS wells as CO_2 does not route via the platform. An example would be a shutdown where power has to be removed from the Acorn CCS project systems such as the HPU, which would result in all Acorn CCS wells valves closing.

In addition to subsea valve closure via MCS signals an ability to depressurise the Acorn CCS umbilical hydraulic lines at the platform will also be provided. This will provide the ability to close Acorn CCS tree valves even with a failure of the MCS to transmit signals.

6.4 Venting Philosophy

Whilst design of process equipment for CO_2 systems (without hydrocarbons present) is very similar to the design of hydrocarbon process equipment, it differs fundamentally as CO_2 is not a flammable or explosive gas. In a loss of containment event, there is no risk of escalating any fire or explosion event, significantly reducing safety issues. As CO_2 does not present an escalation risk, the Acorn CCS project vent design shall not include a conventional automatic blowdown system.

However, CO_2 is denser than air, and consideration needs to be given to asphyxiation and toxic hazards, as CO_2 “clouds” could develop at ground level. Dispersion of CO_2 shall be modelled during the Define phase of the project, which shall inform both the plant layout and vent system design.

Operational and emergency venting will be minimised where possible.

6.4.1 Gas Gathering Venting

When the CCP and/or C&C plants are shut down, flue gas emissions will be vented via the bypass stack on the existing SEGAL and FUKA sources. Flue gases will also be vented from the FUKA glycol and hot oil furnaces when both SEGAL GTs are offline, due to the minimum turndown case for the Acorn CCS onshore facilities.

6.4.2 Capture Plant Venting

The following vent demands exist within the capture plant:

- Solvent absorber vent
- Equipment overpressure protection
- Maintenance venting

A continuously operated vent will be located on the solvent absorber column, releasing depleted flue gas to atmosphere following the CO_2 absorption process. Open to atmosphere, this column operates at close to atmospheric pressure and will not require additional overpressure protection. The DCC is connected to the absorber column and therefore is also open to atmosphere, unless isolated; and as such it will be pressure rated to the maximum operating pressure of the gas gathering system.

Pressure vessels and pipework within the capture plant shall be designed with pressure relief. Any vented CO_2 shall either be vented to a safe location or tied into the absorber column vent. Any vented solvent shall be routed to a new closed drains sump within the capture plant.

It is anticipated that solvent storage vessels shall require provision of a nitrogen blanket to provide an inert atmosphere and minimise vaporisation of solvent. The vent on such vessels shall either be vented to a safe location or tied into the absorber column vent, in accordance with API 2000 [5].

Maintenance vents shall be provided for all vessels and pipework. These shall either vent to a safe location or tie into the absorber column vent.

6.4.3 C&C Plant

The following vent demands existing within the C&C plant:

- HP compression venting
- Equipment overpressure protection
- Maintenance venting

At normal suction pressure and temperatures for both stages of compression, CO_2 solids are not formed.

However, following an HP compressor trip, the CO_2 inventory will cool down to ambient temperature. Subsequent depressurisation of this inventory could then result in temperatures below the freezing point of CO_2, resulting in solid CO_2 formation within the vent header. This may block depressurisation vent lines/valving.

Whilst this would not result in a loss of containment, it could extend the length of shutdown times, due to the requirement to warm up the solids to remove them. For this reason, the intention is to depressurise the HP compression train upon a trip. Strictly, this is not emergency depressurisation, but “Operational” depressurisation, but the same typical blowdown infrastructure would be required. A detailed review shall be carried out during Define phase to assess how quickly depressurisation would need to occur before CO_2 solids production becomes an issue, whether the system needs to be automated or manual and whether there are potential solutions to eliminate the depressurisation requirement.

Pressure vessels and pipework within the C&C plant shall be designed with pressure relief. Any vented CO_2 shall be routed to a new CO_2 vent header, heater and stack, to be installed upon the FUKA South site. Sizing and location of the vent stack are subject to confirmation during Define, however, some spare capacity shall be included within the vent stack sizing to accommodate future phases of the Acorn project. Refer to Acorn CCS Utilities Technical Note [6].

The oxygen removal package will require a vent route for the reagent storage system, anticipated to be hydrogen. This will be provided either via a local vent or via tie-in to the new CO_2 vent stack.

Maintenance vents shall be provided for all vessels and pipework. These shall tie into the new CO_2 vent stack.

6.4.4 Gas Export Pipeline Vent

As with most pipelines (even normally in hydrocarbon service), there is no requirement to depressurise the export pipeline in an emergency. However, facilities to enable depressurisation of the onshore section of pipeline and the Goldeneye pipeline shall be provided for maintenance purposes. Depressurisation of the Goldeneye pipeline, if required, is expected to take over 40 days to completely flatten the pipeline from liquid phase (90barg) and could result in very cold temperatures at the Acorn CCS vent.

A vent heater shall be designed within the vent header to heat the CO_2 and ensure vent piping does not form ice on the exterior of the venting piping and to prevent formation of solid CO_2 within the vent header. This will be reviewed during Define.

Tie-in to the Goldeneye pipeline shall be completed on the SEGAL site. The SEGAL section of CO_2 pipework shall require an independent isolation and depressurisation route, such that the system can be made safe independent from the FUKA site. Tie-in to the SEGAL vent system has been identified as an option, subject to an assessment of the system design and capacity to confirm if it is suitable for CO_2. Alternatively, either a new standalone SEGAL vent route, or a vent tie-in back to the CO_2 stack on FUKA South, shall be provided. This will be engineered during Define.

6.5 Metering

6.5.1 CapCo Metering

The EU ETS (Emissions Trading Scheme) regulations stipulate a measurement-based methodology for determining the amount of CO_2 transferred to and from the capture plant. Metering will also be required for commercial custody transfer.

The locations where metering will be required are summarised as:

- Continuous emission monitoring systems (CEMS) for flue gas measurement at SEGAL GTs and FUKA furnaces
- CEMS for flue gas measurement at the exhaust stack from the capture plant
- CO_2 gas measurement at the discharge from the capture plant

Online analysis and sampling will be required across the plant.

6.5.2 T&SCo

For the transport system, the amount of CO_2 emissions can be determined either by an overall mass balance of all input and output streams or by the individual measurement of the emissions sources including leakage, vented and fugitive emissions and CO_2 associated with equipment.

Mass flow metering will also be required for commercial custody transfer and fiscal purposes.

The locations where CO_2 flow measurement will be required are summarised as:

- CO_2 gas measurement at the inlet to T&SCo plant
- Liquid phase CO_2 measurement at the entrance to the Goldeneye pipeline
- Liquid phase CO_2 measurement at the well

Monitoring of the plant CO_2 vent may also be required.

Online analysis of O_2, H_2O, NOx, SOx, plus sampling will be required across the plant.

6.6 Isolation Requirements

An Acorn CCS project isolation philosophy will be developed to address design requirements to facilitate the safe isolation of process plant, subsea pipelines and electrical systems.

The isolation philosophy will be compliant with SEGAL and FUKA terminal requirements where equipment is located on these terminals. The philosophy will also comply with industry best practices to ensure all work on any equipment is adequately isolated to prevent injury and exposure of operating personnel to any possible risks arising from toxicity of the process fluids.

6.6.1 Electrical Isolation

Equipment electrical isolation requirements and standards shall comply with existing terminal electrical procedures and applicable national/industrial standards which describes in detail specific requirements and practices to be followed to isolate electricity energy sources.

6.6.2 Equipment and Process Isolation

The process isolation philosophy addresses the process design for the isolation of equipment and piping components when required for maintenance, inspection, replacement, or removal from service. Its purpose is to establish the minimum acceptable standard for providing personnel safety while servicing or performing maintenance on equipment that must be isolated to prevent the unexpected release of energy.

The isolation philosophy will be based is based on the latest industry and Health and Safety Executive (HSE) guidance. Again, isolation requirements must meet SEGAL/FUKA terminal standards where equipment is located on these sites.

In addition to the safety element of plant isolation, a major factor in determining equipment isolation requirements relates to the criticality of that equipment within the production system and the means by which isolation may be timely applied to minimise equipment/plant downtime. Particular attention shall be given to the design of isolation boundaries to minimise inventory to reduce venting or draining volumes to allow access to equipment.

Isolation shall also be provided for critical systems where installed sparing cannot be justified

6.6.3 Safe Isolation Principles

In general, it is preferable to carry out maintenance work only on process plants and systems that have been shut down, isolated, depressurised to atmospheric pressure, free of toxic, inert, or flammable gases and drained. When a shutdown is not practical, the design should incorporate facilities to ensure adequate isolation of a completed train or individual piece of equipment.

The design of the isolation requirements shall be the result of a task analysis of the actions required to isolate, depressurise, and purge the system. This shall also take into account the service conditions (e.g. toxic, corrosive, fouling). Except as noted below, isolation facilities shall include a means for "positive isolation".

Valves identified for isolation shall be provided with locking facilities to facilitate installation of a secure device to prevent inadvertent operation of the valve. The practice of locking valves by their handles shall be discouraged as in practice this usually allows tampering.

Valves designated as locked open (LO) or locked close (LC) as shown on P&IDs, will include dedicated locking device so as to prevent mal-operation. Typical examples include isolation valves on relief valves, instrumented trip functions where a common valve can isolate ESD and DCS transmitters.

6.6.4 Interlocks

Interlocks are required to prevent inadvertent operation of a valve by normal manual or automatic means. Interlocks will be required for relief valves and pig launchers and receivers.

The design of mechanical interlocks shall be such that environmental conditions are considered so that their use is not hampered by corrosion and debris.

6.7 Sparing Philosophy

6.7.1 Reliability and Maintainability (RAM) study

A reliability and maintainability (RAM) study has been completed [7] to determine the facility uptime availability. A key output of the model is the ability to identify the equipment and components which contribute most to overall facility downtime with the information being used to determine the sparing requirements of the equipment. The RAM model will be developed further in following phases of the project and will also be used to determine the optimum spare part holding requirements. These will be determined using reliability centred maintenance (RCM) techniques taking into consideration replacement time and lifecycle costing for each of the components.

The flowrates and system capacity constraints are based on the historical emission rates from SEGAL and FUKA x capture efficiency 90% x Acorn onshore plant availability [8]. The historical emission rates from SEGAL and FUKA effectively model the downtime from the emission source equipment.

6.7.1.1 Availability definitions

The operational availability is defined as the proportion of the time in which the plant remains operational to the total time in the period e.g. 365 days or 8760 hours in a year:

$$Operational\ Availability = \frac{Actual\ Annual\ Operational\ Hours}{8760\ hours\ in\ a\ Year} \times 100\%$$

The operational availability includes partial availability when, for example, only one SEGAL GT is available.

The production availability (where production refers to the CO_2 captured and sequestrated for the purposes of this scheme) is defined as the proportion of the actual/achievable yearly CO_2 sent to storage to the maximum theoretical possible CO_2 captured and sequestrated i.e. CO_2 "production" at 100% facilities capacity. This therefore does include partial production operations:

$$Production\ Availability = \frac{Actual\ Annual\ Production}{Annual\ Production\ Capacity} \times 100\%$$

6.7.1.2 Summary availability results

The RAM study availability results are shown in Table 6-2. Operational and production availability are both at 92.1% assuming the following equipment configuration:

- A spare 100% SEGAL flue gas fan shared between the 1x100% fans required for each GT exhaust
- A single 1x100% CO_2 export compressor

Due to the well minimum turndown (0.25MtCO_2/yr), in Year 1 where only Acorn CCS Phase 1 CO_2 is exported, availability it limited to 79%. This is no longer the case from Year 2 onwards, when Acorn Hydrogen and/or other sources come online.

Parameter	Availability Year 1	Availability Year 2 onwards
Operational Availability	79%	92.1%
Production Availability	79%	92.1%

Table 6-2: Availability Results

The operational availability and production availability are the same, as the spare flue gas fan mitigates the partial loss of flue gas to the CO_2 capture plant from an unavailable SEGAL GT flue gas fan. Installing a spare fan in a duty/stand-by arrangement allows production availability to be equal to operational availability, with Acorn CCS project system effectively operating as a single train.

6.7.1.3 Key mechanical equipment sparing

Sparing decisions for key mechanical equipment is based on economic justification in terms of improved availability and turndown requirements to ensure the plant can operate over the required design operation range [9].

Economic analysis was completed for sparing decisions for the major rotating pieces of equipment. A spare 100% flue gas booster fan improves production availability by 0.9% and a spare 100% CO_2 export compressor by 0.7%. The high cost of a spare CO_2 export compressor train showed clearly that a spare compressor could not be economically justified whilst a spare booster fan is around 20% of the cost of a compressor and the economic case for a spare fan therefore was greater. Subject to ducting design and layout studies during Define phase a spare 100% SEGAL emissions booster fan will be considered.

Other equipment sparing decisions are based on turndown requirements and standard engineering practice. The capture plant sparing will be reviewed during Define phase once vendors have been engaged [7].

6.7.1.4 Other equipment sparing

The sparing of other equipment such as coolers, heat exchangers, pumps and columns follows engineering convention and requirement to meet the minimum turndown flow case.

Each of the major equipment items were reviewed during Select. In general, the following philosophy was adopted:

- All pumps were 100% spared
- Fin fan coolers were not spared however as each unit has multiple fans sparing of the main rotating mechanical equipment is provided.
- Reboilers and heat exchangers are not spared
- CO_2 absorption columns in the CCP are not spared however because of the large size of the columns, and associated transport logistics constraints, it is estimated up to three 33% trains may be required.
- Dehydration and oxygen removal processes are not spared

The equipment sparing decisions are therefore:

- 1x100% WHRU on each SEGAL GT emission source
- 1x100% flue gas booster fan on each of the FUKA and SEGAL emissions sources, plus 100% spare between the 2 SEGAL GT emission sources
- 2x100% heating medium pumps
- 3x33% solvent absorbers (subject to vendor confirmation)
- 3x33% DCC (subject to vendor confirmation)
- 2x100% DCC circulation pumps
- 1x100% DCC circulation fin fan cooler
- 2x100% solvent absorber Inter-stage and wash water circulation pumps
- 1x100% solvent stripper column
- 2x100% rich solvent & lean solvent circulation pumps
- 1x100% stripper Reboiler
- 1x100% lean solvent and lean-rich heat exchangers
- 1x100% CO_2 compression
- 1x100% oxygen removal package
- 1x100% dehydration package
- 1x100% injection well
- 1x100% export chiller (Intermittent summer use only)

6.7.2 Turndown Assessment

The design turndown flowrate for Acorn CCS is 108,000t/yr CO_2 export equivalent to a single SEGAL GT operating at 40% turndown [8]. Overall, this represents a 73% turndown on the maximum peak facilities flowrate. It should be noted that turndown refers to the percentage reduction from the maximum facilities design case, so for example a 75% turndown would be a flowrate of 25% of the maximum facilities design flowrate.

A 1x100% integrally geared compressor has a turndown of only 30%, however it can operate down to 100% turndown (zero flow) by operating in recycle. Beyond 30% turndown the compressor power consumption would remain the same at lower export flowrates as the flow through the compressor would remain unchanged. Less than 30% turndown covers approximately 91% of all flow scenarios during typical operating year. For the remaining 9% of the time the compressor would operate in recycle. Power savings are relatively small and do not justify using multiple small compressors, for example multiple 50% compressors [9].

A turndown assessment was completed to determine whether the remaining sparing decisions would also meet the required 73% turndown for the facilities. Figure 6-2 has been colour coded showing **GREEN** where the equipment configuration, easily meets the turndown target. **ORANGE** where the equipment turndown is slightly less than 73%. An example of this is the pumps where indicative turndown for pumps is 66% which does not quite meet the required 73%. It is expected when vendor engagement takes place during Define phase the turndown target will be met. The equipment items coloured **RED** are equipment items which clearly do not meet the 73% turndown. In these situations, mitigation measures have been identified, for example, compressors can operate in recycle to provide greater turndown.

The injection well has a minimum injection rate for the wells of 250,000t/yr which represents a turndown of 30%. The well tubing diameter is sized to ensure single phase operation occurs in the well tubing. Below 250,000t/yr two phase flow would occur possibly resulting in vibration and low temperatures [10].

Well turndown over the short term may be accommodated by line pack combined with periodic well cycling. However constant opening and closing of the wells may cause mechanical and reservoir issues [4].

As reservoir back pressure increases over time the minimum flow well constraint will increase and eventually disappear; this, however, will take many years.

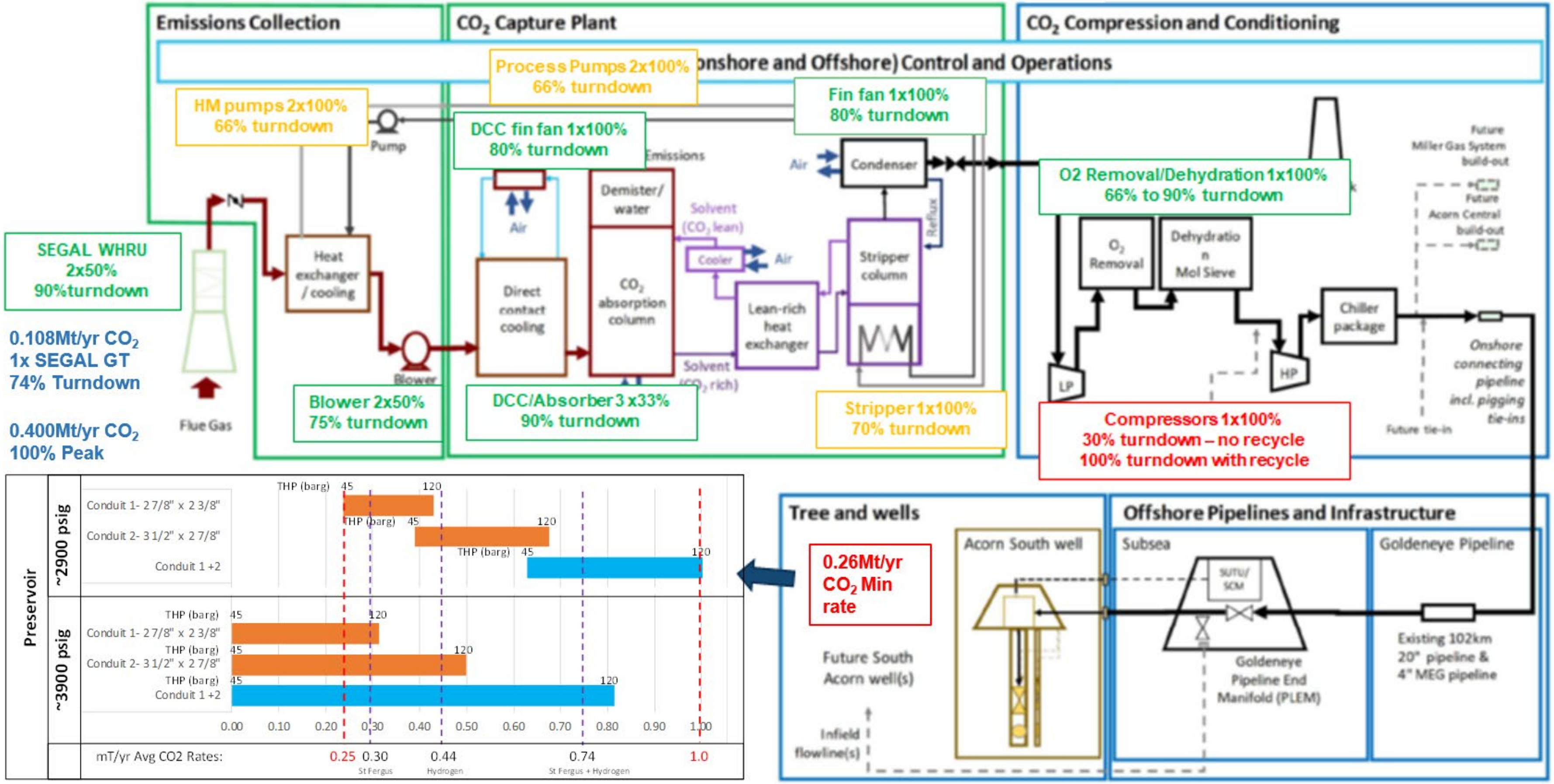

Figure 6-2: Summary of sparing and turndown decisions

7.0 Maintenance Philosophy

7.1 Maintenance Strategy

The project objective is to maximise CO_2 delivery economically and with exemplary safety standards and performance. This shall be achieved by defining a maintenance philosophy which give rise to:

- Compliance with all applicable legislation and policies regarding HS&E,
- Compliant with SEGAL and FUKA terminal requirements where required,
- To safeguard the technical integrity of Acorn CCS facilities over the life of the facilities,
- To contribute to meeting the commercial obligations in terms of availability and reliability,
- To provide an auditable system of asset performance and maintenance control,
- To record and analyse maintenance data on asset performance in order to input such data into further build out developments and to eradicate incipient failures by applying proactive maintenance and integrity management.

7.2 Onshore Maintenance Philosophy

7.2.1 General Philosophy

Maintenance philosophy will make a substantial contribution to the economic operation of the facilities and will vary depending upon equipment type, service, location equipment criticality, and required availability. Activities will be based around RCM efforts.

It is expected that the core team maintenance staff will handle all routine maintenance, requiring only specialised or contract maintenance personnel for the non-routine and any major maintenance activity (e.g. Turnarounds, campaign maintenance etc.).

The strategy appropriate to each item of equipment will be established based on specific inspection and maintenance practices, RCM results, manufacturers recommendation, etc. and will be included in the maintenance reference plan. The strategies will result in a combination of all, or some, of the following maintenance options:

- On-line condition-based performance monitoring of key equipment will be employed where it is demonstrated to be cost effective. Appropriate diagnostic tools and staff competencies will be developed to enable rapid fault finding and rectification,
- Off-line condition-based performance monitoring,
- Intelligent predictive maintenance tools to predict emergent failures and/or give early warnings based on inputs from on-line & off-line condition-base monitoring.
- Non-intrusive monitoring.
- Preventive maintenance.

- Corrective maintenance (following breakdown or condition assessment).
- Opportunity maintenance during outages.
- On failure repair.

The maintenance philosophy may evolve or change during the operating life of the asset due to influences from regulatory requirements, technology, changes due to Acorn build-out, age of asset, changes in operating conditions, economic considerations, resource availability and capacity. Whatever the influencing factor or combination of factors are, the following precepts shall be adhered to in formulating a fit-for-purpose maintenance strategy:

- The facility availability, developed during Select and confirmed in Define, will set the criticality of certain equipment. This criticality will be considered during the maintenance strategy selection.
- The monitoring of the system and equipment availability and reliability, against design premise will be performed in order to evaluate the effectiveness of the design, the equipment and the maintenance and operations activities.
- As a minimum, inspection and maintenance activities shall be undertaken to adhere to all applicable statutory and legislative stipulations as well as existing terminal and inspection and maintenance practices (where applicable).

7.2.2 Onshore Inspection Methods

The following table illustrates the maintenance strategy that shall predominantly be applied to different equipment types/classes for the Acorn CCS facilities.

Maintenance Strategy	Equipment Type
On-line condition based monitoring and remote assistance	Large rotating equipment – compressors, blowers, pumps
Off-line condition-based monitoring	Static equipment – vessels, heat exchangers, piping and valves
Non-intrusive monitoring	Static equipment – piping
Preventative maintenance	Instrumentation, electrical equipment (including motors) & rotating equipment
Corrective maintenance	All equipment following breakdown or condition assessment
Opportunity maintenance	All equipment provided maintenance routine is not unduly compromised
Operate to failure	Not acceptable

Table 7-1: Maintenance strategies

7.2.3 Onshore Standardisation

Where possible and practicable, the project shall strive to minimise and standardise the variety of equipment in use. This is a key enabler of operability and maintainability, through the ability to standardise operations (production and maintenance) activities and to:

- Reduce the need for different types of spare parts and hence minimise stockholdings.
- Allow inter-changeability of equipment.
- Maximise familiarity with equipment thereby simplifying maintenance efforts.

- Increase the prospect for long term service contracts and supply chain management opportunities.
- Local/regional specialist expertise and capability.
- Eliminate or reduce the potential for incompatible spares to be used e.g. instrument tubing and fittings.

7.2.4 Inventory and Spare Parts

The RAM model will be updated during Define phase and the information used to determine the spare parts requirement, with the spare parts holding requirements being determined using RCM techniques taking into consideration replacement time and lifecycle costing for each of the components.

Spares are categorised into three distinct categories: guarantee or insurance spares, commissioning and start-up spares and operating spares. Insurance spares are generally of high value with extended lead times and are normally purchased with the main equipment.

For any new equipment, it will be a condition of purchase for vendors and manufacturers to advise and provide electronic spare parts lists and interchangeability records.

7.3 Offshore Maintenance Philosophy

7.3.1 General Philosophy

For the offshore elements of the T&SCo, a key feature with regards to maintenance, is that almost all the system elements are under water. The water depth increases from zero at the shoreline to 119m at Acorn South. This adds significant cost and complexity to any maintenance activities and for unplanned maintenance means there is a lead time in mobilising the equipment required to carry out any repairs. For these reasons offshore facilities are generally designed to be maintenance free for the design life. This is achieved by simplification, the specification of high reliability components and the selection of equipment and materials that are robust to the operating conditions and fluids. This may also include the incorporation of additional allowances at the design stage, such as a corrosion allowance on pipe steel, to provide increased resilience.

7.3.2 Pipeline Integrity Management

In operating service, the integrity of the system is ensured by having a Pipeline Integrity Management System (PIMS) in place. This will be developed through the Execute phase of the project. Early work in PIMS development will include Hazard Identification (HAZID) workshops using multi-discipline groups to ensure that all the threats to system integrity are identified and mitigations against those threats are put in place. The probability and potential consequences of each threat is assessed in turn. These threats will be particular to the system however for offshore pipelines and subsea facilities the following are always considered:

- Internal corrosion, through contact with conveyed fluids.
- External corrosion, through contact with seawater.
- External damage, through abrasion or impact from fishing or other sea users.
- Debris close to the pipelines, such as fishing gear or anchors, or occasionally unexploded ordinance (UXO).

- Unexpected deformation, through effect of pressure and temperature in service including interaction of system loads with soil resistance.

The PIMS will describe the steps required to monitor and ensure the integrity of the system including types of monitoring and inspection.

7.3.3 Pipeline Inspection, Monitoring and Maintenance

The type of inspection and monitoring required will be covered within the PIMS, based on the perceived threats to the system and the issues that these may cause. Details of inspection methods and frequencies will be informed through a Risk Based Inspection (RBI) program where the threats are considered and an optimal strategy determined for how often inspection activities will be carried out and how this frequency is adjusted according to the results found or due to changes to the nature of the threats to the system.

7.3.3.1 Inspection and monitoring methods

The following types of inspection and monitoring are common for subsea systems with the frequencies dictated by the RBI:

- Sonar Survey – Conducted from a near seabed sensor towed from a vessel, ROV mounted or through a free flying Autonomous Underwater Vehicle (AUV).
- General Visual Inspection (GVI) – Typically using ROV mounted cameras while travelling along a pipeline route. This may be supplemented by laser scanning.
- Close Visual Inspection (CVI) – Through ROV camera or diver investigation of specific features or components.
- Pipeline burial status survey – Indications of where the pipeline is buried, unburied and where spans have appeared can be obtained from sonar survey as above. Where information on depth of burial is required this can be achieved through supplementary equipment such as a Pipetracker carried by an ROV.
- Cathodic Protection (CP) Survey – Checks on the performance of the CP system through probes used to detect the protection voltage and / or CVI of anodes.
- Internal inspection through In-Line Inspection (ILI) pigging – This is discussed further in Section 7.3.3.2.

As simplification is used to reduce the risk of failures subsea, sophisticated conditioning monitoring such as may be used on onshore rotating equipment is typically not employed. However, the following can be monitored to obtain information on the performance of the systems and through trending can provide early warning of potential issues:

- Measuring and recording the times taken for valves to travel from open to close position, or vice versa.
- Monitoring the pressures and pressure changes in the hydraulic control lines.
- Monitoring the consumption of hydraulic fluids.
- Monitoring the Insulation Resistance (IR) of the power cables.

7.3.3.2 Intelligent pigging

RBI analysis will be carried out to determine the frequency and type of inspection in CO_2 service, recognising that threats may differ from those present during hydrocarbon transport service. It is also recognised that Acorn project use will result in the pipeline design life being extended.

ILI, as known as intelligent pigging, is the use of electronic tools or ‘pigs’ pushed through the pipeline in order to inspect the condition of the pipe internal surface. The pigs are bespoke items specified for a particular pipeline inspection run through selecting the most appropriate modules accounting for the pipeline material, the types of defects expected, the diameter and length of the pipeline, the fluids present and the pressure and temperatures.

The pig will run along the entire length of the pipeline propelled either by the normal pipeline contents or a temporary substitute fluid such as treated water. Depending on the sensors used it may be necessary to run the intelligent pig within a slug of fluid between pigs ahead and behind the main pig. This helps ensure reliable functioning of the inspection tools in a controlled environment.

For the 20” Goldeneye pipeline an ILI run is planned for 2021 to assess its current condition. The ILI will provide the remaining wall thickness along the pipeline length and also detect features on the pipe wall such as areas of increased corrosion, pits etc. ILI can provide such detail down to millimetre level and the results are processed and analysed post run to reveal the pipeline conditions. For the 20” pipeline this ILI run will provide a baseline of the condition pre-start and allow a comparison and investigation of the effects of CO_2 transport.

ILI inspection requires bespoke tooling, launch operations at St. Fergus, the need for a Diving Support Vessel (DSV) to recover the pig at the ASM and the subsequent processing and analysis. Risk based analysis, considering the internal corrosion threat, will drive the frequency of ILI.

ILI intervals will be guided by the results of each ILI run but would typically be at intervals of 5 – 6 years through the life of the pipeline. Facilities will be required to launch and receive the intelligent pigs at any point through the operating life. These need not be permanent facilities due to infrequent use.

It is considered that prudent to plan an ILI run after the first few years of operation to verify design estimates of corrosion in CO_2 service. This will confirm that with appropriately conditioned CO_2, corrosion is minimal.

7.3.3.3 Pipeline maintenance

The pipeline is existing and therefore there is no opportunity to alter the design. Whilst external threats may be found to be as Goldeneye previous gas service, internal threats are expected to differ.

Replacement of any significant section of pipeline will be a complex and costly operation. Therefore, efforts will be focussed on steps to mitigate risks and avoid issues. Where analysis shows that localised damage or internal corrosion may occur there is the option to hold in stock a subsea repair clamp. This is a device, sized for the pipeline, that can be deployed around the outside of the pipeline at the location of a defect. The clamp attaches to the pipeline and contains sealing elements. The clamp therefore can act as a secondary barrier where there is a risk of the primary barrier (the pipe steel wall) failing in service. Such clamps are typically of a few metres length and therefore are only suited to localised defects, such as may occur from an unusually severe external impact (dent).

Mitigation of pipeline risk will also be through due consideration of running ductile fracture (RDL) failure. Primary consideration will always be to prevent any loss of containment and therefore there should be no event that initiates RDL. However, in the event of CO_2 loss, the pipeline should be robust to the failure extending. Repair of a localised loss of containment can be carried out using a clamp or similar, however a long running fracture failure is much more problematic as this may require a new pipeline section to be installed. Therefore, RDL risk is to be reduced to an acceptable level [11].

Mass balance calculations based on flow measurements onshore and at the well will also be used for leak detection.

7.3.4 Offshore Infrastructure Maintenance

Although the basic premise of the subsea facilities will be for maintenance free solutions it is recognised that breakdowns can occur. The assessment of means of repairing/replacing subsea facilities, and the associated sparing to be carried, will be a function of a system criticality assessment. This will address:

- Failure modes for installed equipment.
- Historical data on reliability and failure rates (establish Mean Time Between Failures – MTBF).
- Criticality of the component to continued operation.

Due to the difficulties in making repairs in-situ in a subsea environment a general philosophy is for replacement of components with a new item with replaced equipment recovered and taken onshore for investigation and repair or refurbishment. Repaired items may then be used as future spares. Such an approach means that subsea facilities are designed with a modular approach.

In considering what spares to carry key factors are:

- The impact of the component being out of service or operating in a degraded state.
- The lead time to obtain a replacement if one is not held in spares (potentially months to over a year in some cases).
- The time required to affect a repair or replacement.
- The means by which replacement will be carried out.

The above will typically result in high criticality components that have a history of failures being kept onshore as replacements. These items will be identified after analysis but would typically include:

- A complete replacement Subsea Control Module (SCM).
- A replacement choke valve.
- Replacement section of jumper bundle cables or tubing.

The means of replacing these components will be considered in design and may be achieved by:

- ROV or Remote Operated Tooling (ROT) intervention, deployed from a vessel.
- Diver intervention deployed from a DSV.
- A combination of the above.

Replacement by ROV/ROT has the advantage that a wider range of vessels may be used to carry out the work. Allowing for such replacement requires that the components, and the supporting structure, be designed for this form of removal. This includes the provision of connectors that can be made-up and released by an ROV.

Define phase and Execute phase engineering will determine the components to be designed for ROV/ROT removal; this typically includes SCMs and choke valves on Christmas trees (XTs). Components that are less likely to require removal, such as spools connecting XTs to the manifold, will typically be designed for diver assisted removal. Therefore, in the event of damage to such a component (unlikely within a typical injection life) there is a means to recover and replace.

There will be no planned activities to carry out maintenance or replacement of components at specified intervals. Therefore, any maintenance required will either be because of system monitoring and inspection predicting that component failure or degraded operation is impending, or a reaction to a sudden component failure. In the former case the intervention will ideally be scheduled to coordinate with other activities. This may be to align with a shutdown of the onshore plant or to fit with the schedule of an intervention vessel and conduct the work as a 'fly by' activity rather than a dedicated vessel mobilisation.

Where there is a sudden component failure then there will be an assessment of the criticality to continued safe operation. A typical example may be an SCM failure. This will result in the well no longer being operable and therefore require that the SCM be replaced as soon as possible in order to recommence injection. In this case a dedicated intervention may be required, although synergies with subsea vessel interventions at other offshore facilities would always be explored.

The means by which this intervention is carried out will be dependent on the Acorn T&SCo system operator and any contractual relationships that they have in place. This may include a standing agreement for intervention vessel access, potentially through co-operation with other operators. Alternatively, a vessel may be obtained on a spot market basis for such a one-off maintenance activity.

7.3.5 Offshore Platform Interface

Day to day control of the offshore facilities will be from an Acorn CCS project control room at St. Fergus. Control and monitoring of the subsea wells will be achieved through:

- A link from the St. Fergus control room via a wireless communications from shore to the platform (satellite, 4G, LoS).
- Hardwired link from the platform to the ASM and onto individual wells via an umbilical.

The following Acorn equipment will be placed on the platform:

- MCS
- Hydraulic power unit (HPU)
- Electrical power unit (EPU)
- Topsides umbilical termination unit (TUTU)
- Chemical injection unit (CIU) (if required).

A service agreement will be put in place between the Acorn T&SCo operator and offshore platform operator to cover maintenance of the Acorn equipment. This will include monitoring, interfacing and arranging for equipment supplier technicians to visit the platform to carry out maintenance and repairs if required.

7.4 Well and Reservoir Management

7.4.1 Well Integrity Management

The life cycle design, construction, operations and decommissioning of wells will be performed to ensure well integrity throughout this period. This will include independent verification throughout the well life cycle by an appropriate Well Examiner. Well records will be maintained within a dedicated Acorn CCS “Well Integrity Management System (WIMS)” and used as evidence by the Well Examiner to confirm the well meets industry standard well integrity requirements.

7.4.2 Well Inspection and Maintenance

During operations the key routine well inspection and maintenance activities will consist of (a) annulus pressure monitoring (b) XT valve testing (c) SSSV testing.

In addition, non-routine well maintenance may be required due to failure of completion equipment, however, this non-routine rig or non-rig well intervention activity is not covered due to its bespoke nature.

Detail of both the above routine and non-routine inspection and maintenance activities is provided within the Acorn CCS “Well Operating Guidelines” [3], however, for convenience a summary of the routine well inspection and maintenance activities is provided below.

7.4.2.1 Annulus pressure monitoring

During well operations cooling and heating stresses will be observed by the well’s wellhead and downhole completion equipment which will result in cooling and heating of the fluid contained within the “A” annulus. To safely manage the pressure within the “A” annulus a nitrogen gas cap has been installed which should avoid any “over-pressuring” which could result in casing failure. Any changes in the “A” annulus pressure may be due to a leak in the tubing string which may result in corrosion of the casing and subsequent well failure. Routine monitoring and inspection of the “A” annulus pressure is essential to ensure the well’s integrity.

7.4.2.2 XT valve testing

Xmas Trees (XTs) are one of the key components (safety critical elements/barriers) in ensuring well integrity. It is critical that, along with the well design and wellhead, they provide barriers between the storage volume and the environment. In normal operation XT main valves will be open to allow CO_2 flow into the well. However, these valves must reliably close in the event of an incident to isolate the well and storage reservoir from any location where there has been a loss of containment. Therefore, periodic testing of the XT valves is required. This can be conducted remotely.

7.4.2.3 SSSVs testing

Due to the important safety critical element/barrier role of the SSSV in reducing the risk of a large volume escape of CO_2 during a loss of containment it is important to periodically test the valve to ensure that it will close on demand. Operation and testing of SSVs is covered in industry recommended practice API RP 14B. SSSVs are designed to be fail-safe and are held open by hydraulic pressure supplied via the High Pressure (HP) control line.

SSSV can be tested as follows:

- Close the XT wing valve.
- Remove pressure from the control line.
- Allow the SSSV to close.
- Conduct a leak test of the SSV by reducing pressure (bleed off to sea).
- Record pressure changes above the SSSV.
- Equalise pressure across the SSSV prior to re-opening the valve.

7.4.3 Well and Reservoir Management

The well and reservoir will be managed to ensure CO_2 is safely contained within the store. This will be achieved following a comprehensive "Containment Risk Assessment" which will result in the development of a comprehensive "Measurement Monitoring and Verification (MMV) Plan". Contained within the "MMV Plan" will be a "Well and Reservoir Management Plan".

The aim of the "Well and Reservoir Management Plan" is to ensure optimal CO_2 injection to meet contractual agreements while maintaining overall system integrity (wells, reservoir and facilities). This will be accomplished through an active well and reservoir monitoring program implemented from project start up through to cessation of injection. This will consist of certain baseline data acquisition (incl. 4D seismic, MBES and SSS data) in addition to continuous acquisition of pressure, temperature, rates and other required data in the wells and reservoirs. The acquired data will be used to calibrate the well and reservoir models which can then be used to forecast CO_2 plume injection performance which can then be used to assess ongoing conformance against the real-time well and reservoir monitoring data.

Key Value drivers for the "Well and Reservoir Management Plan" are:

- Ensuring well integrity
- Ensuring facility (platform) integrity
- Maintaining CO_2 delivery for injection
- Active well and reservoir models update

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8.0 Health Safety and Environment

The operating companies, CapCo and T&SCo, will ensure the relevant management systems are in place to operate and maintain the project in accordance with corporate HS&E requirements and regulation.

The HS&E processes and management systems will achieve the following:

- Ensure identified project risks are effectively managed.
- Where project risks are identified as tolerable if As Low As Reasonably Practicable (ALARP) effective documented demonstration of the ALARP case is required.
- Create a strong reporting culture which supports and informs a culture of continuous improvement.

8.1 HS&E Premise

The HS&E premise is structured around achieving the HS&E policy of the operating company. In line with the PBDE HS&E Policy, the premise and objectives are:

- Compliance with all applicable Health, Safety and Environmental Regulations, relevant UK Regulations, Standards and relevant International and site operator Codes and Standards as required, supplemented by good practices.
- To ensure that all relevant operational decisions are taken duly considering HS&E aspects and that their rationale is documented.
- To ensure that significant risks/hazards potentially related to the operation of the Acorn CCS plant are properly identified and minimised/controlled according to the ALARP principle.
- To identify all potential safety, health and environmental hazards associated with the operation of the project by means of adequate analysis and studies, and to develop prevention, control and mitigation measures to eliminate or minimise harm to people, damage to plant or equipment, loss of production or adverse effects to the environment.
- To encourage the adoption of a positive, proactive and committed health, safety and environmental culture throughout the operation of the project.
- Bringing to the attention of appropriate personnel any feature which could affect the safety or environmental performance of operations, so that all reasonable precautions can be taken to eliminate or minimise its effects.
- Ensuring, as a minimum, that the individual responsibilities under current legislation are understood and complied with and that personnel have relevant competencies for the operational activities required.

8.2 Health Safety and Environmental Management

8.2.1 Health

There are a number of potential health hazards associated with exposure to chemicals during the CCS operations, especially those at initial filling, commissioning and during plant turnarounds where exposure to fluids is greatest. There is an expectation that the design phase will embed the necessary physical mitigation measures required to minimise the risk of exposure and to minimising potential leak paths. However, strong operational procedures and controls during these activities will be required to reduce the risks to personnel.

Personnel health and safeguard requirements will be managed in accordance with regulatory requirements. Risk associated with normal operational task associated with chemicals, like loading and unloading of vessels, will be managed through controlled and approved procedures.

A Working Environment Health Risk Assessment (WEHRA) will be completed to identify the tasks performed by operations and maintenance personnel that may expose them to working environment health hazards. Key health hazards anticipated from the project include:

- Exposure to amines and potentially to degraded amine compounds (e.g. nitrosamines).
- Exposure to process chemicals (e.g. methanol, propane, Triethylene Glycol etc).
- Exposure to CO_2
- Noise

The two key areas for consideration will be amine and carbon dioxide (CO_2), and further information is provided in relation these in the following sections.

It is recognised that the St Fergus gas terminals and the offshore platform are existing installations where health hazards are already closely controlled in accordance with operating procedures and management systems. It will be important that the interfaces between existing and new plant are effectively managed with appropriate interface management processes.

In addition to the already mentioned WEHRA the following further studies assessing health related issues associated with the plant will also be undertaken.

- Health Impact Assessment (HIA): This assessment will be undertaken as part of the Environmental Appraisal for the project. The HIA shall identify and assess the potential impact of the project on neighbouring communities. Due consideration will be given to both construction and operational phases and potential short and long term effects. Mitigation measures to minimise potential impacts and maximise health benefits will be included within the impact assessment process.
- Air Quality Modelling: Air quality modelling will be undertaken as part of the Environmental Appraisal for the project. The modelling will assess changes to emissions profiles as a result of the project and to assess the impact these could have on human health.

8.2.1.1 Amine

The CCP will be using an amine-based solvent to extract the CO_2 from the flue gas stream. The exact amine solvent to be used has not been selected at the time of writing. Amines can be harmful when swallowed, toxic in contact with skin and corrosive. There is the potential to cause severe burns and eye damage if direct contact occurs.

The second important aspect in relation to amines is the potential for direct contact with Oxides of Nitrogen to form N-nitrosamines. These can form in aqueous and air emissions steams. N-nitrosamines are possible carcinogens. Close consideration will be required of nature of any amine emissions to air and water, the reaction profile of such amines with Oxides of Nitrogen within the project (and from neighbouring facilities) and the effects of naturally occurring removal processes such as photodegradation. Maintenance and operational procedures will be required to avoid contact or inhalation during removal of a degraded amine sludges through the carbon capture process. In addition, any maintenance, equipment isolation and breaking of containment involving vessels for amines or amine degraded products will need careful consideration through the WEHRA to ensure they can be performed safely.

8.2.1.2 Carbon Dioxide (CO_2)

CO_2 is a toxic gas at high concentrations, as well as an asphyxiant gas when oxygen is displaced to dangerous levels. At concentrations above 7% in air (i.e. 70,000ppm) CO_2 poses a significant danger to humans. At this level exposed workers become incapable of making rational decisions or carrying out action to promote escape or evacuation. The Health and Safety Executive have set Workplace Exposure Levels (WEL's) for CO_2 as 5,000 ppm for 8hr time weighted average and 15,000 ppm for short term 15-minute time weighted average.

In addition to hazards posed by inhalation of CO_2, there are additional hazards associated with dense phase CO_2 that are likely to occur when CO_2 is handled in large quantities and at high pressure. These hazards can arise when a release occurs, and the pressure suddenly falls or is lost completely. These hazards include cryogenic burns, embrittlement of pipe work and toxic contamination.

As with amines, it will be important that any maintenance, equipment isolation and breaking of containment involving vessels or pipeline with CO_2 (particularly dense phase CO_2) are careful consideration through the WEHRA to ensure they can be performed safely. It is expected that a detailed procedure will be put in place for any operational In-Line Inspections (ILI) of the Goldeneye pipeline as this activity has the potential to increase leak risk from the dense phase pipeline networks.

8.2.2 Safety

The project will have a number of distinct aspects, namely flue gas collection, CCP, C&C plant, CO_2 export and transport, CO_2 storage. All these elements will need to be safely operated and maintained in accordance with a well-defined safety management system which meet Health and Safety Executive expectations and accords with an international standards, such as ISO45001.

The project will be located within and in close proximity to existing top tier COMAH facilities. The operator will be required to fulfil the regulatory requirements in relation to safety and in particular to fulfil the requirements of the Health and Safety at Work Act. In addition, the operator will be expected to interface closely with the existing operations at the St Fergus gas terminal complex to maximise safety (e.g. consistent and closely interfaced permit to work procedures should be adopted).

At the time of writing, CO_2 is not included as a regulated substance within COMAH regulations. Although it is noted by the Health and Safety Executive as having major accident hazard (MAH) potential in certain phase states. There is also potential that the presence of amine (and/or degraded products) on the project could qualify the project as a COMAH facility. This will be confirmed upon appointment of the CCP technology vendor.

Given this recognised MAH potential and the H&S policy of the operating entity it is expected that operation of the project will accord with the COMAH regulations. The interface with the existing facilities and associated impacts of their COMAH Safety Cases will also need to be carefully managed. The operation of the CCS plant would be expected to become part of the existing COMAH forums in place at St Fergus gas terminal complex to management potential safety events across facilities and domino effects.

The offshore development is subsea and does not include any new populated installations. Any vessel operations and operations at the umbilical tie back platform, will be undertaken in accordance with the platform operator's safety management systems. There will a duty on the overall project operator to ensure these systems meet the required standards for the project.

Throughout the Define and Execute phases a number of studies will be completed which will identify potential safety hazards and associated mitigation, safety critical equipment and tasks. This will include HAZID, HAZOP and SIL workshops and assessment, Quantitative Risk Assessment (QRA), ALARP demonstration as well as Safety Critical Task Analysis, the identification of Safety and Environmental Critical Equipment and performance standards. These studies will also inform any hazardous area classifications, which will need to take account of both new hazardous area classifications within the project and proximity to existing hazardous areas within existing facilities. The operation and maintenance of the project will need to adopt and build up the findings and requirements from these studies.

8.2.3 Environment

The objective for the operating company will be to deliver, operate and maintain the project without adverse impact to the environment and to comply fully with regulations, international obligation and existing St Fergus operator and CCS operator standards. Objectives for the project will include:

- Minimising the risk of emissions to the environment from the plant through effective controls and processes.
- Maintaining appropriate records, monitoring and measurement of environmental aspects to ensure compliance with permits and regulations and to support reportable incidents should they occur.
- Ensure that effective and compliant waste management chains are maintained from source to final disposal for any process and hazardous waste streams.

It is anticipated that the operating entity will have a corporate ISO14001 (or OSPAR) certified Environmental Management System. This system will ensure that suitable processes are in place to achieve:

- Legal compliance.

- Prevention of pollution.
- Continuous environmental improvement.

Given the integration of the CCS project within existing facilities at St Fergus there will be a requirement for integration of environmental limits and performance monitoring to ensure overall compliance for all parties and appropriate accountability for any variation from standards at points of emission.

8.2.3.1 Legal Framework Related to CCS

There are a number of international and regional legal frameworks which are relevant to CCS activities and many definition and prohibitions within these frameworks that can influence CCS operations. Some of the key regulatory frameworks with regards to the environment include:

- The London Convention.
- The London Protocol.
- The Paris Agreement.
- UN framework Convention on Climate Change.
- Oslo and Paris (OSPAR) Convention.

There are also a number of EU Level Directives which have been bought into UK statute. Close monitoring of the relevant UK legislation will be required as the Withdrawal Agreement from the EU comes into force. However, it should be note that within the UK and EU there is increasing policy support for the deployment of CCS in particular:

- The European Green Deal.
- The UK Climate Change Act, as amended.

8.2.3.2 UK Environmental Legislation

Applicable UK regulatory requirements are detailed in The Permits and Consents Register (Document Number: ACCS-X-00-PB-PM-KK-0003). This register will continue to be updated through the life of the project. Regulations specific to the project are noted in the following sections:

Onshore: The environmental effects of the project will be assessed and reported within an environmental appraisal of the onshore plant (inland of Mean Low Water Springs). This document will be produced to satisfy the requirements of the Town and Country Planning (Scotland) Act, as amended, and form part of the planning application submitted to Aberdeenshire Council. There will be an obligation on the operator of the plant to commit to and achieve any operational conditions associated with planning consent of the project.

The onshore plant will also need to maintain compliance with Pollution Prevention and Control (PPC) (Scotland) Regulations as regulated by Scottish Environment Protection Agency (SEPA) during operations. There are existing PPC permits in operation at St Fergus and the interface between the Acorn CCS permits and existing site PPC permits will need to be closely managed as the project will alter and amend existing emissions points.

Offshore: The project will need to operate in accordance with the requirements of a CO_2 storage permit. This permit will be in accordance with the Storage of Carbon Dioxide (Licencing etc) Regulations, as amended. There is a requirement for a regulator Environmental Impact Assessment (EIA) to be undertaken of the offshore elements of the project (offshore from Mean Low Water Springs). This EIA will be undertaken in accordance with the requirements of the Offshore Petroleum Production and Pipelines (Environmental Impact Assessment and other Miscellaneous Provisions)

(Amendment) Regulations. There will be an obligation on the operator of the offshore plant to commit to and achieve any operational commitments made within the offshore EIA to mitigate environment effects. In addition, the Energy Act 2008 updated a number offshore regulations (e.g. Offshore Marine Conservation (Natural Habitats, &c.) Regulations) to encompass CCS and there will be a requirement on the operator to maintain compliance with such legislation.

8.3 Security

The project will form part of the St Fergus gas terminal complex. This facility is recognised as critical national infrastructure. This increases the emphasis on security at the facilities and there is 24 hr police/ministry of defence security in operation. The operation of the CCS project will need to accord with security standards set by this level of classification. The project will require a robust security strategy to address security threats such as armed conflict, terrorism, criminal activity, civil unrest and cyber security and data theft.

8.4 Emergency Response

The operating company will require a comprehensive Emergency and Crisis management plan.

Plans will be developed for the CCS plant which will address the close proximity and required interactions between the Acorn CCS project and the FUKA and SEGAL facilities at the St Fergus gas complex. Contractual agreements will need to be developed to address command and control concepts.

Emergency plans shall be developed prior to any construction activity and credible scenarios practiced ensuring all aspects of command and control are operative and personnel are trained and competent to deal with incidents.

The introduction of new CO_2 related hazards will require a different mind-set to that of a hydrocarbon and utility process plant. The natural behaviour of CO_2 upon release and the potential for it to stall combustion engine vehicles will require careful consideration and adjustment in emergency response. There will need to be wider consultation with emergency services and the public to address emergency response methods in relation to CO_2 events.

The project will provide the appropriate organisation, facilities, procedures and training.

Offshore operations at the umbilical tie-back platform will be integrated into the existing operator's emergency response plan.

8.5 Simultaneous and Combined Operations (SIMOPs and COMOPs)

A SIMOPs strategy will be required for the project. This will define the boundaries and activities where simultaneous operations may take place which will allow concurrent activities to be performed safely and without interference. There will be a requirement to address this both on and offshore during construction and operations.

In relation to COMOPs there is potential for multiple construction and operational activities to be occurring as the Acorn project builds out and the existing facilities maintain their existing assets. There will be a requirement for effective management systems in relation to these activities.

SIMOPs on the umbilical tie back platform will be managed under the operators existing strategy.

8.6 Permits & Consents

There will be a requirement to develop a management system to handle the Operational Permits, Consents and Regulatory Compliance. This would be anticipated to be a tracking system which shall be used to ensure timely application for new permits and consents, and renewal of expired ones. This can build upon the permits and consent register already in place and a recommended part of the ISO14001 environmental management system implemented on the project. The project could require modifications to existing facility operator permits and these should also be tracked and monitored as any such amendments will require regulatory approval.

8.7 Social Performance

The St Fergus gas terminal complex has been an important part of the local community and society in the area for several decades. It will be important that the social performance of the Acorn project maintains and improves this relationship with the surrounding community whilst also offering the climate change benefits to society as a whole. The project will be expected to operate as a good neighbour and to minimise adverse impacts. The project is undertaking local stakeholder engagement activities to inform the local community of the project and to identify and address potential concerns. In addition, an emphasis is being placed on supporting local employment and supply chain opportunities within the project. The operation of the project will be expected to maintain a strong dialogue with the local community and support the local supply chain.

It is recommended that a social performance plan is developed in line with the operating company's corporate social responsibility requirements. This plan should create a basis from which to monitor, measure, adjust and improve social performance activity over time. An important aspect of such a plan will be the set-up of a grievance procedure to allow members of the community to report concerns and issues with the project which can be subject to robust investigation and corrective measures.

9.0 Abbreviations and Acronyms

Acronym	Definition
ALARP	As low as reasonably practicable
ASI-01	Acorn South injector no.1
ASM	Acorn South Manifold
ATEX	Atmospheres Explosives Directive
AUV	Autonomous Underwater Vehicle
BEIS	Department of Business, Energy and Industrial Strategy
BS	British Standards
CapCo	CO_2 capture company
CATOX	Catalytic Oxidation
C&C	Compression and Conditioning
C&E	Cause and Effect
CCP	Carbon Capture Plant
CCR	Central control room
CCS	Carbon capture and storage
CCSL	Carbon Capture Solutions
CES	Crown Estate Scotland
CfD	Contract for difference
CO_2	Carbon dioxide
COMAH	Control of Major Accident Hazards Regulations
CMMS	Computerised maintenance management system
CP	Cathodic Protection
CVI	Close Visual Inspection
DAS	Distributed acoustic sensor
DCC	Direct contact cooler
DCS	Distributed Control System
DP	Differential pressure
DSV	Diving Support Vessel
DTS	Distributed temperature system
EA	Environmental appraisal
EIA	Environmental impact assessment
ENVID	Environmental impact identification
EPU	Electrical power unit
ESD	Emergency shutdown
ESDV	Emergency shut-down valve
EU ETS	European Union Emissions Trading Scheme
FEED	Front end engineering design (referred to as Define in the Acorn CCS project)
FID	Final investment decision
FO	Fibre optics
FSA	Flue gas decarbonisation service agreement
FUKA	Frigg UK Association
WHP	Wellhead pressure

GHG	Greenhouse gas
GT	Gas turbine
GVI	General Visual Inspection
H_2	Hydrogen
HAZID	Hazard identification
HMG	UK Government
HMI	Human Machine Interface
HoT	Heads of terms
HP	High pressure
HPU	Hydraulic power unit
HS&E	Health, safety and the environment
HSE	Health and Safety Executive
ILI	In-Line Inspections
JT	Joule Thomson
JV	Joint venture
LER	Local Equipment Room
LP	Low pressure
LSIR	Location Specific Individual Risk
LTEL	Long term exposure limit
MAH	Major accident hazard
MCS	Master control station
MMV	Measurement Monitoring and Verification
MOU	Memorandum of understanding
MTBF	Mean Time Between Failures

MTF	Mean time to failure
MTR	Mean time to repair
NGG	National Grid Gas
NSMP	North Sea Midstream Partners
O&M	Operation and maintenance
O_2	Oxygen
OEM	Original Equipment Manufacturer
OGA	Oil and Gas Authority
opex	Operating expense
OSA	Operations services agreement
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic
P&ID	Process and Instrumentation Diagrams
PBDE	Pale Blue Dot Energy
PCI	Project of Common Interest
PCV	Pressure control valve
PDHG	Permanent downhole gauge
PLC	Programmable logic controllers
PLR	Pig launcher-receiver
PIMS	Pipeline Integrity Management System
RAM	Reliability, Availability and Maintainability
RBI	Risk Based Inspection
RCM	Reliability centred maintenance
RDL	Running ductile fracture

ROT	Remote Operated Tooling
ROV	Remote Operated Vehicle
ROW	Remote Operator Workstation
SCM	Subsea control module
SCSSSV	Surface controlled subsurface safety valve
SEGAL	Shell Esso Gas and Liquids
SEPA	Scottish Environment Protection Agency
SIF	Safety integrity function
SLD	Single Line Drawings
SSSV	Subsurface safety valve
STEL	Short Term Exposure Limit
T&SCO	Transport and storage company
TASSA	Transport and storage service agreement
TD	Total depth
TDSA	Technical Development Services Agreement
TEG	Triethylene glycol

THP	Tubing head pressure
THT	Tubing head temperature
TRSV	Tubing retrievable safety valve
TUSA	Transport utilisation and storage agreement
TVD	True vertical depth
UPS	Uninterruptible power supply
UXO	Unexploded ordinance
WEHRA	Working Environment Health Risk Assessment
WHP	Wellhead Pressure
WHT	Wellhead temperature
WHRU	Waste heat recovery unit
WIMS	Well Integrity Management System
WRSV	Wireline retrievable safety valve
XO	Crossover
XT	Christmas tree

10.0 References

[1] OGA, “Carbon Dioxide Appraisal and Storage Licence CS003,” 2018.

[2] Pale Blue Dot Energy, “Control Philosophy; ACCS-S-00-PB-IC-PH-0002 Rev R02,” 2020.

[3] Pale Blue Dot Energy, “Well Operating Guidelines, ACCS-D-30-PB-WE-RP-0002,” 2020.

[4] Pale Blue Dot Energy, “Export Pipeline Operating Technical Note; ACCS-S-00-PB-YY-PH-0001,” 2020.

[5] American Petroleum Institute, “API 2000 : 2014(R2020) Venting Atmospheric and Low-Pressure Storage Tanks,” 2020.

[6] Pale Blue Dot Energy, *Utilities Tie-in Technical Note; ACCS-S-10-PB-PR-TN-0001,* 2020.

[7] Costain, “ACCS-S-00-CO-YY-RP-0004 RAM Study,” 2020.

[8] Pale Blue Dot Energy, “Design Premise, Doc No; ACCS-SS-00-PB-YY-BD-0014 Rev R01,” Nov 2020.

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[10] Total, “ACCS-D-30-PB-WE-RP-0002 R01 Preliminary Well Operating Guidelines,” 2020.

[11] Pale Blue Dot Energy, “Export Pipeline Operating Guidelines; ACCS-S-00-PB-YY-PH-0018,” 2020.

[12] Pale Blue Dot Energy, “Control Room Decision Note; ACCS-S-10-PBYY-DN-0013,” 2020.