Acorn CCS Project

Document Title: D24 Concept Options Report

Document Number: ACCS-X-00-PB-PM-KK-0002
KKD Date of Issue: September 2021
BEIS ref. no: CS336
Knowledge Category: Carbon Capture and Storage

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	

Important Notice

Signed by Storegga COO

Pale Blue Dot.

acorn

Acorn CCS FEED

D24 Concept Options Report
ACCS-X-00-PB-PM-KK-0002

Original Issue Date: November 2019

KKD Issue Date: September 2021

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Document Summary			
Client	Department for Business, Energy and Industrial Strategy (BEIS)		
Project Title	Acorn CCS FEED		
Title:	D24 Concept Options Report		
Distribution:	BEIS	**Classification:**	Public
Original Date of Issue:	8th November 2019		
KKD Date of Issue:	17th September 2021		
Prepared by:	J Park, A Marshall, T Walker, M Edwards, R Gilbert, D Pilbeam		
Approved by:	R Gilbert/S Murphy		

Amendment Record					
Rev	**Date**	**Description**	**Issued By**	**Checked By**	**Approved By**
V0.3	31/10/19	Workshop Pre-read - For Comment	R Gilbert	T Walker	R Gilbert
V1.0	05/11/19	Draft for Comment - Partners	W Hazell	T Walker	R Gilbert
V1.2	08/11/19	Partner Comments Included	T Walker	W Hazell	R Gilbert
V2.0	08/11/19	Issue to BEIS	W Hazell	R Gilbert	S Murphy
R01	01/04/21	Revision to KKD	R Jennings	W Hazell	W Hazell
A01	17/09/21	Issue to BEIS	R Jennings	W Hazell	D Clarkson

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1.0 Executive Summary

The Acorn CCS Project has the opportunity to capture up to 345 ktCO_2/yr from existing flue gas emission sources at St Fergus Gas Terminal. CO_2 will be conditioned, compressed, then transported offshore for storage in the Acorn CO_2 Storage Site via the existing Goldeneye pipeline.

The project is currently in the Concept Select phase, during which technical options for the project will be evaluated, with the aim of selecting a single design concept to take into the Define phase of the project.

The technical options under consideration for the Define phase are discussed within this report with a tabular summary provided in Appendix 1. These include the onshore, subsea and subsurface design for Acorn CCS project. Commercial and financial models for the project are also discussed.

Acorn CCS project is a carbon capture and storage project located at St Fergus Gas Terminal which has the opportunity to capture up to 345ktCO_2/yr from existing industrial emission sources. This is a significantly increased level of industrial emissions capture than originally considered for the project which sought to capture between 40-200ktCO_2/yr. The captured CO_2 will be conditioned, compressed, then transported offshore for storage in the Acorn CO_2 Storage Site via the existing 100km Goldeneye pipeline. The Acorn CCS project is currently at the Concept Select phase for the increased level of capture. During this phase, technical options will be evaluated a single design concept will be selected in preparation for the Define phase. During the Define phase, the Front End Engineering and Design (FEED) of the selected concept will be undertaken. Through this systematic concept selection process, which integrates the increased capture opportunity, the most robust and fit for purpose concept for the initial phase of the Acorn CCS project will be selected.

This report provides the technical options available for Acorn CCS project. The selection process for decision making is documented, and the different technical options available are discussed including onshore facilities, subsea, subsurface, commercial and financial.

For the onshore plant, the key decisions to be made during the Concept Select phase of the project include the selection of carbon capture technology, quantity, quality and source of flue gas emissions, site location, cooling & heating system design premise, design life and availability.

The subsea infrastructure selection will primarily be based on selection of the sub-surface safety valve (SSSV), and whether electrical/hydraulic supply is available from nearby platforms. This report will also consider the provision of hydrate inhibitor to the wellhead, power transmission and communication methods.

The subsurface options to be defined include well type, number of wells, well flowrate envelope, well availability, completion design (inflow & outflow), well location, well monitoring, well control & subsea filtration requirements.

The commercial options to be defined include project agreements with third parties, development of the investment case for the project, including the project build-out and development of supply chain arrangements, the financing plan and the CCS business model in conjunction with BEIS. Pre-investment for future build-out will be considered as it can be influential in some areas of the concept selection.

2.0 Introduction to Acorn CCS

2.1 Project Summary

Acorn CCS project is a phased carbon capture and storage (CCS) project based in the north-east of Scotland as shown in Figure 2-1. Acorn CCS project is being designed to securely store captured CO_2 in the Acorn CO_2 Storage Site licenced area, as defined by the Oil and Gas Authority (OGA) Licence Agreement (OGA, 2018) and the Crown Estate Scotland (CES) Lease.

It is proposed that St Fergus, located 64km north of Aberdeen, will be the onshore focus for Acorn CCS project and that existing, redundant, offshore gas pipelines will be re-purposed for transporting CO_2 to the Acorn CO_2 Storage Site licenced area.

This project will be led by the Acorn CCS project delivery team managed by Pale Blue Dot Energy (PBDE). The project is being funded by the EU as a Project of Common Interest (PCI) and the UK Government, via the Department of Business, Energy and Industrial Strategy (BEIS) as part of the CCUS Innovation Fund and Industry.

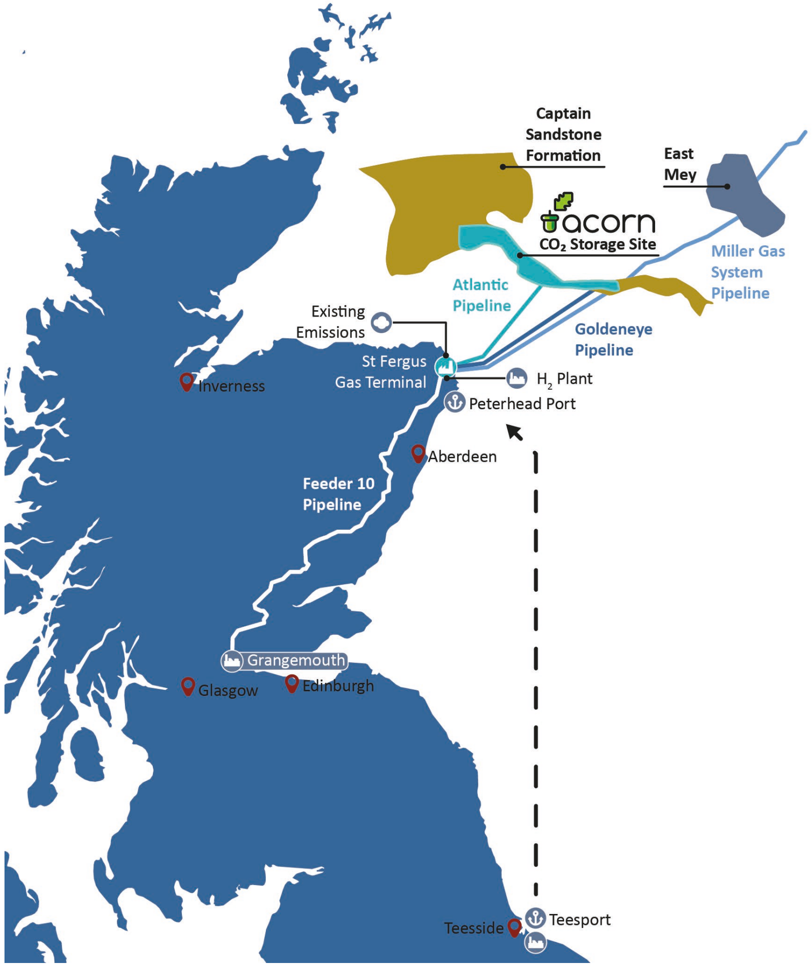

Figure 2-1: Acorn CCS Project map

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

1. Flue gas collection from one or more existing St Fergus industrial emitters and transport of the flue gases to the CO_2 capture plant
2. Pre-conditioning of flue gas, if required, prior to CO_2 capture plant
3. CO_2 capture plant using a liquid solvent
4. 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
5. Onshore tie-in to the offshore pipeline (including pigging tie-ins/facilities if required)
6. Offshore infrastructure, including the re-use of the existing Goldeneye pipeline and connection to one or more wells
7. Drilling and completion of) one or more wells, capable of injecting an anticipated 0.04–2MtCO_2/yr complete with the subsea tree(s)
8. Subsurface work for the Acorn South CO_2 Storage Site and scoping work for the build-out
9. Well control

The scope of the Acorn CCS Project study also includes, but is not limited to:

1. Integration of the collection, capture and compression facilities with the relevant St Fergus host facilities, including:
    - civils
    - constructability
    - control room and control integration
    - utilities
2. Metering of CO_2 at the change of ownership points and for reservoir monitoring purposes
3. Onshore health, safety and environment (HSE) aspects to deliver a consentable, compliant design for Acorn Phase 1
4. Offshore HSE aspects to deliver a consentable, compliant design for the Acorn South development and well control infrastructure (umbilical).

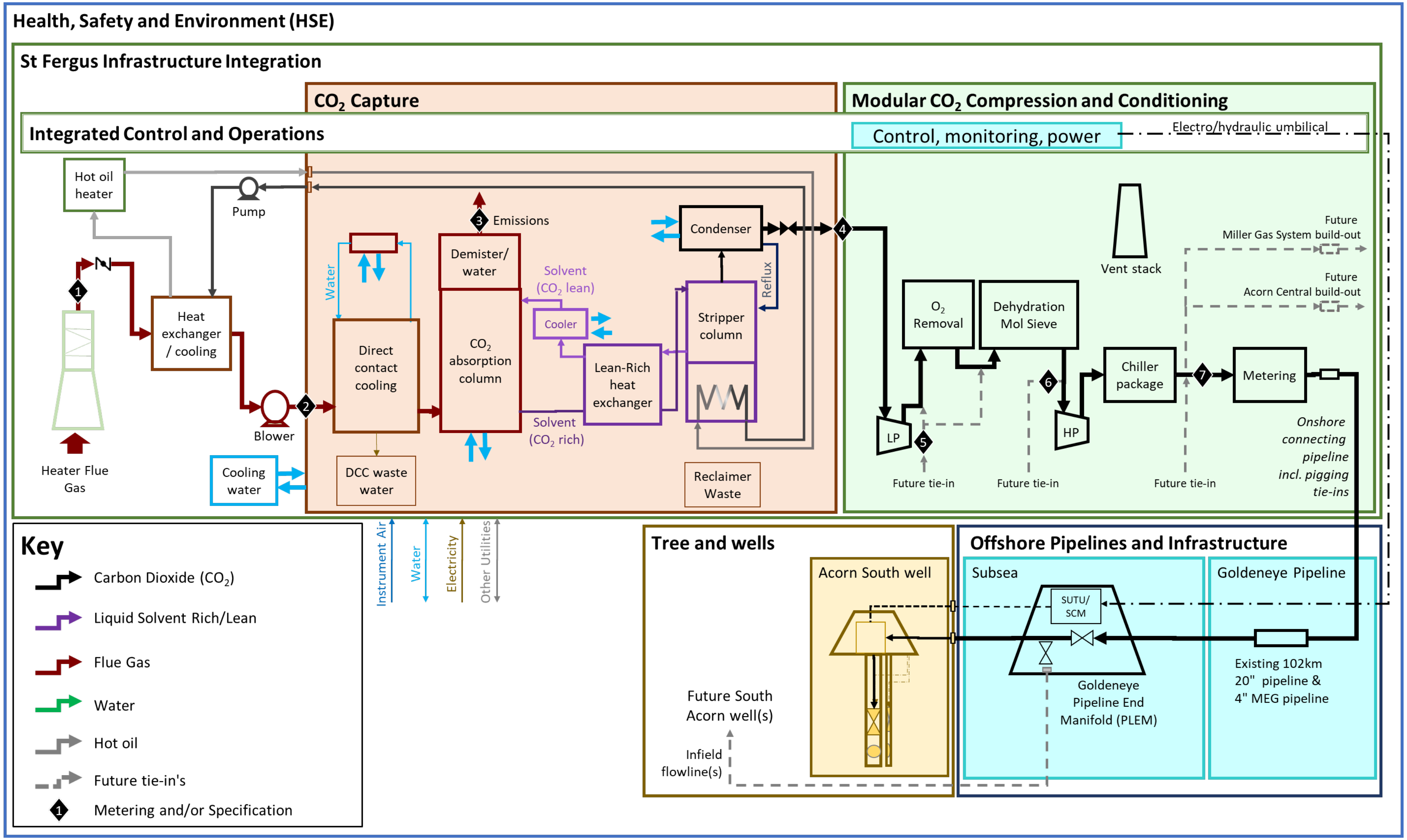

Figure 2-2: Indicative Acorn CCS Project Phase 1 Block Diagram

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:

1. Carbon capture from a new hydrogen plant (reforming natural gas) at St Fergus and onwards transport of the CO_2 to the Acorn CO_2 Storage Site licenced area (known as Acorn Hydrogen)
2. Re-purposing of the National Gas Grid (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
3. 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
4. Using the Peterhead shipping infrastructure to support the export of CO_2
5. Drilling and completion of additional well(s) capable of injecting, nominally $2MtCO_2$/yr within Acorn South
6. Offshore infrastructure, including new in-field flowline to one or more Acorn South well(s)
7. Drilling and completion of further wells capable of injecting, nominally $2MtCO_2$/yr each, at Acorn Central. The areas that represent Acorn South and Acorn Central are shown in Figure 2-3.
8. 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
9. An international interconnection utilising the Miller Gas System pipeline

Development of the offshore infrastructure and drilling and completion of additional wells will 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: Indicative Acorn Central and Acorn South Map

3.0 Scope

3.1 Purpose

The purpose of this report is to present the technical and non-technical options which have been identified for assessment within the Acorn CCS project. These options have been generated following a number of technical and non-technical workshops by the project team and industrial partners, the latter of whom advised that emissions during Phase 1 could be increased from ~40ktCO_2/yr (NSMP emissions) to ~340ktCO_2/yr by the inclusion of SEGAL emissions. This Concept Select process is being undertaken following a request from industry partners to re-examine concept options before proceeding to the Define or FEED phase of the project. It was agreed that the onward success of the project would depend on from a thorough review of the concept options. In addition, this document details the process which will be used to select the concept taken forward to the Define phase during which Front End Engineering and Design (FEED) will be undertaken.

The options considered in this document relate to:

- Onshore
- Offshore
- Subsurface
- Route to market
- Finance and economics

3.2 Project Schedule

The capital value process being followed to mature the project is shown in Figure 3-1.

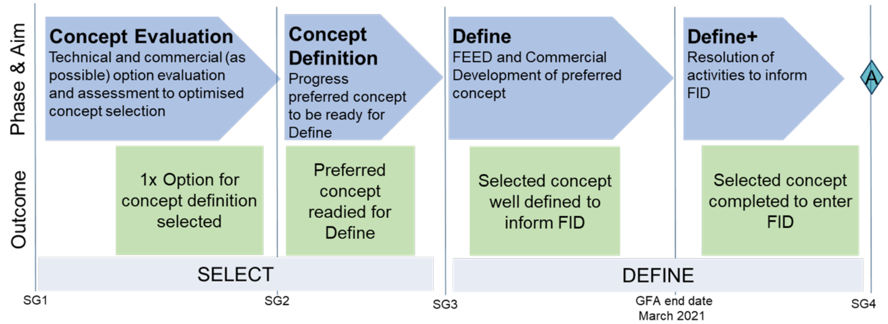

Figure 3-1: Acorn Project Capital Value Process

3.3 Project Decisions

In light of the opportunity to now increase the level of emissions captured by the project, a series of new project decisions are now required to select the preferred concept for Define (FEED) studies. These decisions are categorised within a decisions hierarchy as follows:

- Givens
- Focus Decisions
- Tactics

Note: It is not the intent of this process to repeat work on options which have been previously studied for Acorn CCS project, rather it is to ensure that decisions previously made, remain robust against the potential for improved project outcomes.

3.3.1 Givens

Based on input from industry partners during the 29 October 2019 Concept Identification Workshop key decisions characterised as *Givens* are:

- CO_2 capture at St Fergus Gas Terminal
- Liquid solvent technology for flue gas CO_2 capture
- CO_2 compression is electrically driven
- Dense phase CO_2 transport via the Goldeneye pipeline
- Phase 1 CO_2 storage is within Captain Sandstone at Goldeneye
- No re-use of Goldeneye offshore facilities (e.g. platform & wells)
- Subsea development
- Phase 1 involves a minimum of one injection well
- The project has negative greenhouse gas emissions during construction and operations
- Currently no commercial basis for industrial CCS in the UK
- Compliance, as a minimum, with HSE regulations

3.3.2 Focus Decisions

Based on input from industry partners during the 29th October 2019 Concept Identification Workshop, focus decisions were discussed, however further work is required to confirm this assessment.

3.3.3 Tactics

Based on input from industry partners during the 29th October 2019 Concept Identification Workshop tactics were discussed, however, further work is required to confirm this assessment.

All decisions to be assessed during the proposed work programme (incl. focus decisions & tactics) are listed in the following “Select Phase Deliverables” section.

3.4 Select Phase Deliverables

3.4.1 Technical Definition

3.4.1.1 Onshore Options

The scope for Concept Select phase includes the following aspects:

- Quantity & source of emissions
- Location of CO_2 capture and compression plants (based on technical and commercial input)
- Cooling and heating systems design premise
- Availability, turndown and design life

Other elements to be covered in the Concept Select phase are:

- CO_2 capture technology
- Effluent treatment
- Export compositional specification
- Dehydration/O_2 removal
- Compression
- Metering technology

- Control integration
- Power

The following additional utilities are also required for Acorn CCS project and will be reviewed as part of the site location decision and what services are available at the sites. However, it is considered likely that the final decisions for some of the following will be deferred until after the site location decision has been made:

- Firewater
- Instrument air
- Nitrogen
- Demineralised water
- Potable water/service water
- Emergency power
- Uninterruptible power supply (UPS)

3.4.1.2 Offshore Options

The scope for Concept Select phase includes the following aspects:

- Subsea control design premise
- Umbilical routing
- Inhibitor requirement and provision
- Pipeline pigging, including confirmation of the timing of the Goldeneye pipeline intelligent pig survey

A list of all technical decisions and options currently identified (onshore and offshore) is included in Appendix 1 – Options Summary Tables .

3.4.1.3 Subsurface Options

The deliverable scope for Concept Select phase includes the following aspects:

- Preliminary well location for Acorn Phase 1
- Preliminary second well location for Acorn South
- Well design for phase 1

3.4.2 Non-Technical

3.4.2.1 General

The scope for the Concept Select phase includes the following aspects:

- Contracting strategy for FEED
- Degree of pre-investment and longer-term value proposition for Acorn Phase 2
- Preferred business model(s) to enter Define phase (subject to engagement with BEIS)
- Identify joint venture (JV) structure, relationship, risk allocation, financing, and funding – consistent with development of business model

3.4.2.2 Route to Market, finance, and economics

The deliverable scope for Concept Select phase includes the following elements:

- Line of sight to CCS business model agreement with BEIS – commercial architecture and risk allocation
- The preliminary investment case for project build-out (Phase 2)
- Project agreements in place required to secure (as required) St Fergus CO_2 capture, compression and conditioning, CO_2 supply, utilities, operations support, access and power supply
- The commercial framework to support access to Goldeneye pipeline (as required)
- Supply chain Concept Select phase contracts to be put in place

- Supply chain arrangements and technology licence arrangements (as required) in place for Define phase
- Commercial risk management

The deliverable scope for Concept Select phase includes the following elements:

- CCS business model - economic assumptions, modelling and option analysis
- Development and preparation of preliminary financing plan

4.0 Selection Process

4.1 Decisions Quality

A decision quality process will be adopted for Acorn CCS project (based on the "Strategic Decisions Group" methodology) which will be captured in a "Decision Note" (DN) for each and every decision. This will enable consistent, evidence-based and robust evaluation, so that all decisions are made to a high standard throughout the project, and/or where there are opportunities to improve the quality of those decisions. Figure 4-1 presents an example of the decision quality diagram which has been adopted.

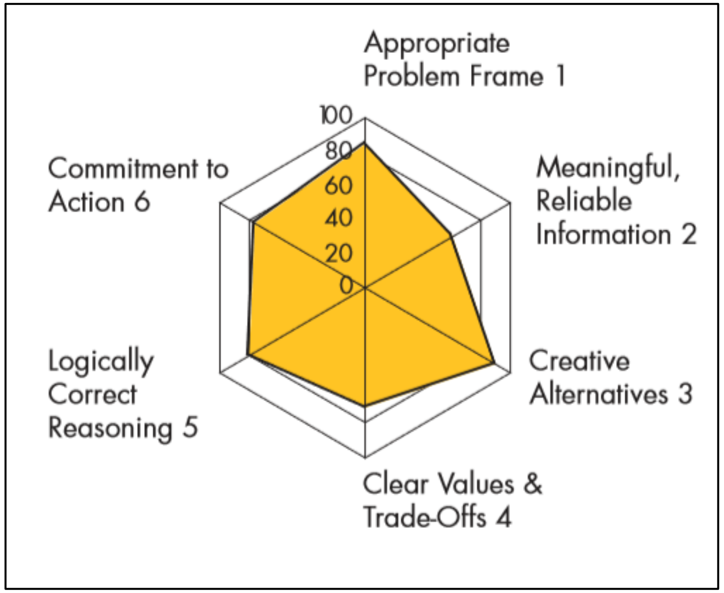

Figure 4-1: Decision Quality Diagram

The key criteria which will be considered within a DN for each decision are:

1. Appropriate problem frame
2. Meaningful, reliable information
3. Creative alternatives
4. Clear values & trade-offs
5. Logically correct reasoning
6. Stakeholder commitment to action

4.2 Partner Engagement

The project is being led by PBDE with support from industry partners. The project benefits from the opportunity to utilise the expertise of the industry partners, either providing support and assurance or in specific cases, taking a more active role in workstream delivery.

4.3 Project Value Drivers

In conjunction with industry partners, several value drivers have been established to drive the decision-making process. These are presented in Figure 4-2.

The value drivers will be used to assess the full range of technical and commercial options generated during the Concept Select phase with the goal of selecting the final concept options to be taken into the Define phase.

Item	Value Driver
A	**Capex**: Lowest capex for Phase 1
B	**Schedule**: Phase 1 project delivered by mid 2020s
C	**HSE**: Risk of planning, permitting, environmental, regulatory, public or other stakeholder objections minimised and HSE performance (construction and operational) maximised (a consentable design is a go/no go decision)
D	**£/tonne**: Lowest £/tonne (capex, opex throughput) for Phase 1
E	**GHG Reduction**: Net GHG reduction for Phase 1
F	**Future Build Out**: Flexibility for subsequent phases of development (Low regret cost)
G	**Operability**: Low risk to lifetime operability and availability for Phase 1
H	**Market Stimulation**: Offers greatest potential for CO_2 transport storage market and knowledge transfer to build the market

Figure 4-2: Acorn CCS Project Value Drivers

5.0 Source of Emissions Options

The intention of the Acorn CCS project is to capture significant quantities of post combustion CO_2 from the existing St Fergus gas terminals. This is considered to be an option from either the Shell-Esso Gas and Liquids (SEGAL) terminal, which is owned by Shell-Esso and operated by Shell, and/or the Frigg UK Association (FUKA) terminal owned by North Sea Midstream Partners (NSMP) and Gassco and operated by PX Limited. This site is referred to as NSMP in this document. The Scottish Area Gas Evacuation System (SAGE) terminal (owned by Ancala and operated by Wood) and the National Grid Gas Terminal are not considered, based on dialogue with these parties, to have long term CO_2 sources of a level which would support the investment in capture for this project.

The options which are under consideration for capture as part of the Acorn CCS project are shown in Table 5-1 and their locations are highlighted in Figure 5-1. This shows the total CO_2 emitted and the quantity of CO_2 which can be captured (approximately 90%).

Emissions Source	Cumulative Total CO_2 Emissions (tCO_2/yr)	Cumulative 90% of Total CO_2 Emissions (tCO_2/yr)
Both (2) SEGAL GTs	340,800	306,720
A single (1) SEGAL GT	170,400	153,360
Both (2) NSMP Glycol Heaters	13,763	12,387
Both (2) NSMP Hot Oil Heaters	29,341	26,407
NSMP Combined (Both NSMP hot oil & both glycol heaters)	43,104	38,794
Total combined (SEGAL GTs & NSMP Heaters)	383,904	345,514

Table 5-1: St Fergus Emission Source Options (comms. from site operators)

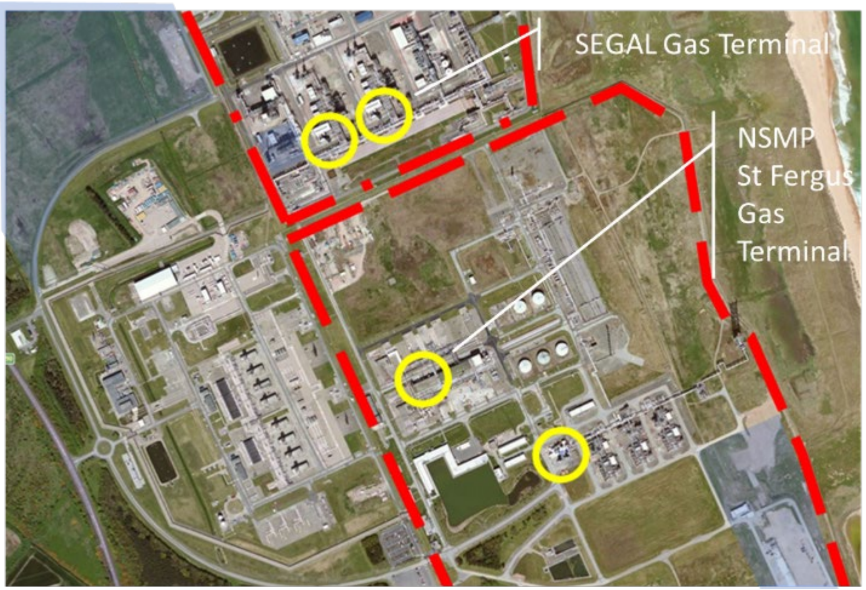

Figure 5-1: St Fergus Flue Gas Sources (Image: Google)

The volume of emissions and the emission sources have a significant impact on the project.

5.1 SEGAL Options

The SEGAL site has multiple CO_2 flue gas sources, but they are dominated by only two points of release (Figure 5-2), with the two gas turbines driving compressors representing most of the CO_2 volume emitted from the SEGAL site.

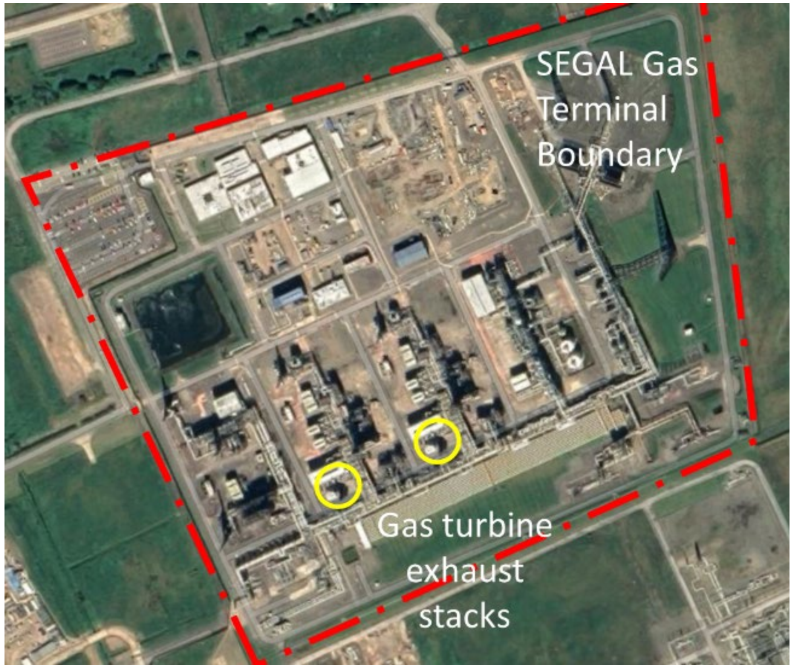

Figure 5-2: SEGAL Flue Gas Emission Sources (Image: Google)

Each gas compressor has two exhaust stacks (Figure 5-3); one of which is a straight flue gas stack and one of which has a waste heat recovery unit (WHRU) exhaust stack to recover heat from the flue gas prior to discharge to atmosphere. This heat is captured in a hot oil medium which is then used to regenerate molecular sieve beds on the SEGAL plant. This activity is expected to be carried out infrequently and intermittently, presenting an opportunity to utilise this waste heat within the CO_2 capture plant.

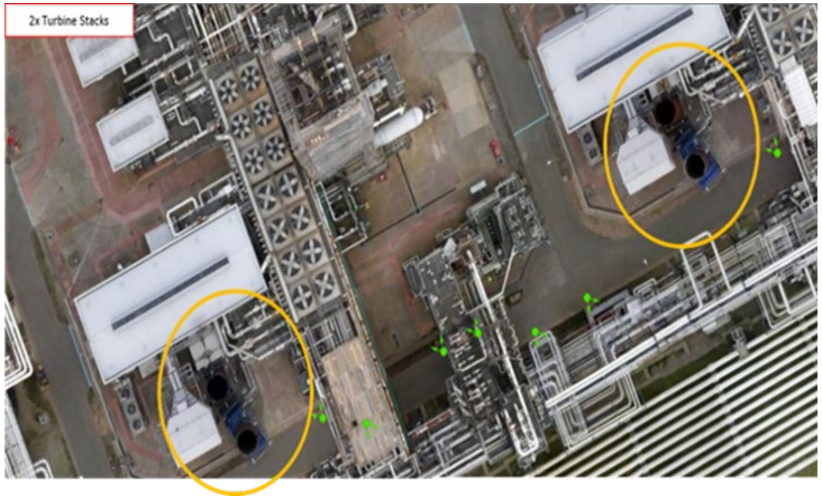

Figure 5-3: SEGAL Gas Turbine Exhaust Stacks (Image: Google)

Capture from both gas turbine exhausts will be considered as an option, equal to a total CO_2 flowrate of 340,800tCO_2/year. An alternative option which will be considered is to design the capture plant for a single SEGAL gas turbine (GT) but route ductwork from both gas turbines to the capture plant.

5.2 NSMP Options

The NSMP site consists of three phases:

- Phase 1 has been decommissioned or incorporated into Phase 2.
- Phase 2 is owned by Gassco and is used to import gas from Norway via the Vesterled pipeline.
- Phase 3 takes gas from the FUKA pipeline which services the Alwyn, Bruce and Frigg oil & gas fields, amongst others, and takes gas from west of Shetland through the Shetland Islands Regional Gas Evacuation System (SIRGES) pipeline.

The phase 2 glycol gas fired heaters (identified in Figure 5-4) are used to heat the gas after being let down from import pressure to sales gas pressure. There is a large seasonal swing on this load as the UK imports more gas from Norway in winter. The heaters can be run as duty/standby, but most often are run together.

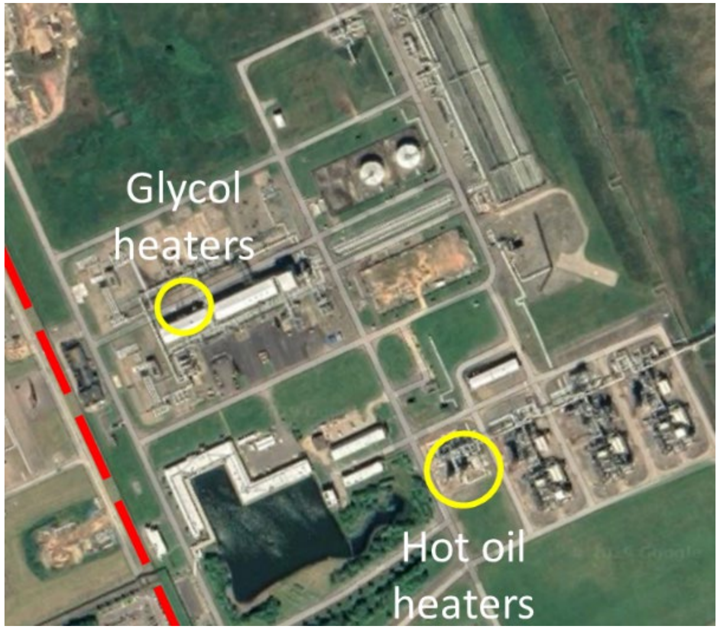

Figure 5-4: NSMP Gas Fired Heaters (Image: Google)

The phase 3 gas is Natural Gas Liquids (NGL)-rich. Gas fired hot oil heaters (Figure 5-5) are used to heat the NGL extraction/de-ethaniser column heaters and molecular sieve regeneration heaters (cyclic load). The gas fired heaters can be run as duty/standby but are most often run together. NGLs are pumped to either the BP operated Forties pipeline system or the Shell facility located at Mossmorran.

Figure 5-5: NSMP Gas Fired Hot Oil Heaters (Image: PX Group)

Capture from both Glycol Heaters (13,763tCO_2/yr) and Hot Oil Furnaces (29,341tCO_2/yr) will be considered as separate options. A combined option considering capture from both will also be considered.

6.0 Site Selection Options

There are number of decisions to be made around the selection of the site for the Acorn CCS project capture and compression plant.

6.1 Site Size

The first decision to be made relates to the amount of space required for the Acorn build-out options.

The options for the site size are:

- Acorn CCS Only
- Acorn CCS and compression/conditioning of the CO_2 produced as part of the Acorn hydrogen plant
- Inclusion of provision for Feeder 10 compression
- Based on previous shipping studies the import/export compression and conditioning have been assumed to take place at Peterhead. Therefore provision of specific land at St Fergus would not be necessary.

6.1.1 Acorn CCS Only

The area required for the Acorn CCS project (Phase 1) CO_2 capture plant is approximately 2,500m^2 (COSTAIN, 2019), whilst the area for the compression and conditioning plant is approximately 12,000m^2– based on an estimation from previous work (Genesis, 2019); for a total area of 14,500m^2.

6.1.2 Acorn Hydrogen

The hydrogen production plant itself is not, based on recent studies, likely to be co-located with the CCS plant due to the different risk profiles of the two sites. The hydrogen plant itself is anticipated to have a footprint in the region of 44,800m^2 (Pale Blue Dot Energy Limited, 2019), for a nominal capacity of hydrogen production of 200MW and an associated CO_2 by product of 0.45MtCO_2/yr. The additional footprint of the plant for the compression of CO_2, from the hydrogen production plant, is likely to be of the same order of magnitude as the Phase 1 conditioning and compression plant, 12,000m^2.

6.1.3 Acorn Feeder 10

Inclusion of the area required for Feeder 10 compression (an additional 6MtCO_2/yr of high pressure compression) has been assessed during previous studies to increase the footprint to approximately 32,900m^2.

6.2 Site Selection

The location options that will been considered for siting of the capture, compression and conditioning plants are:

- Blackhill
- NSMP South
- NSMP North
- SEGAL
- SEGAL 2600
- SEGAL Construction laydown area

- Split Site

These locations are shown in Figure 6-1.

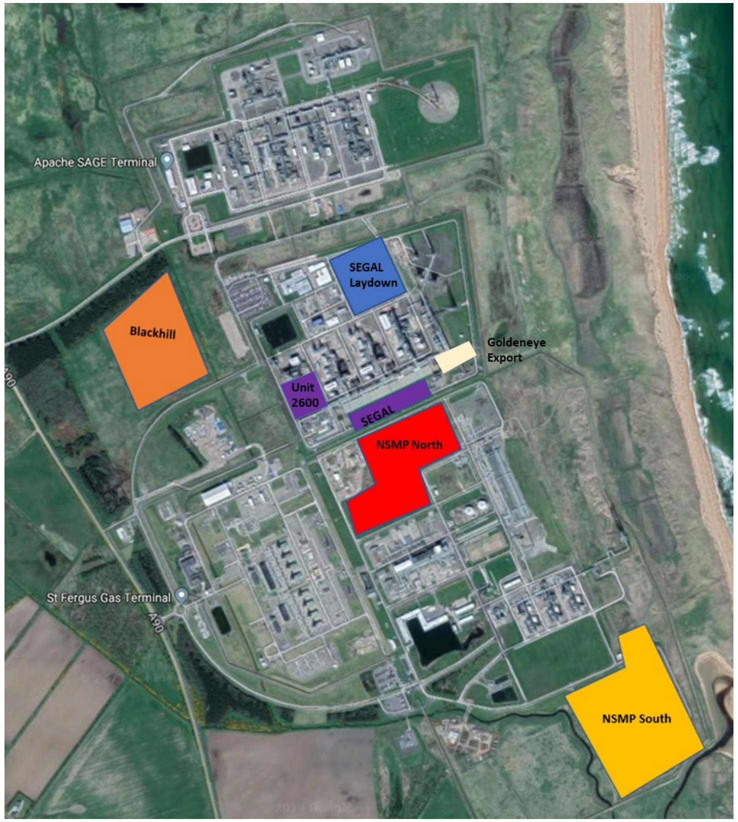

Figure 6-1: St Fergus Potential Site Locations for Acorn (Image: Google)

6.2.1 Blackhill Option

The Blackhill site is owned by National Grid and is located immediately to the north of their existing site at St Fergus. This is the largest of the sites under consideration with an approximate area of 88,000m^2. There is sufficient space to site the capture, compression and conditioning plants on this site.

Blowers would be located local to the flue gas emissions sources. Ductwork would be routed from the sources to the site at Blackhill. Approximately 1.5km of dense phase pipework would be required to tie in the compression plant to the Goldeneye export facilities.

Figure 6-2: Capture and Compression at Blackhill (Image: Google)

Selection of this site reduces construction work in the vicinity of the existing St Fergus process plants.

The Blackhill site is partially impacted by SEGAL hazards including flash fire and explosion overpressure. These hazards will need to be considered during the Concept Select phase, to confirm the risk is as low as reasonably practicable (ALARP).

As the Blackhill site is located outside the security fence boundary of St Fergus, a new security fence is likely to be required around the site.

The Blackhill site is located 3.5km south of the Loch of Strathbeg Site of Special Scientific Interest, which is also designated a European Special Protection Area. Direct impacts from construction are unlikely to impact this site, however, there may be an impact on mobile wildfowl (geese, swans) due to disturbance and loss of foraging habitat.

The area on the eastern side of the Blackhill site is classed as being at risk of flooding - this can be seen on the SEPA flood maps (SEPA, n.d.). Initial indications are that pipework to/from the site would need to cross this floodplain. However, it may be possible to locate infrastructure such that it avoids this area. A flood risk assessment would be completed to assess the flooding risk should this site be selected. Groundwork investigation would also be completed, to assess the potential effects of construction and contamination risk on soils and groundwater.

6.2.2 NSMP South Option

The NSMP South site is located to the south of the St Fergus site and has been confirmed by NSMP as commercially available. The Miller processing facilities were previously located on this site prior to decommissioning. Although decommissioned, some of the Miller reception facilities are still located on the east side of this site.

The site has an available area of 70,000 m^2 which is sufficient to site the capture, compression and conditioning plants. Flue gas from emission sources would be boosted by blowers and sent to the site via large diameter ducting. Figure 6-3 shows the proposed diameter, lengths, and routing of ducting.

Blowers would be located local to the flue gas emissions sources. Ductwork would be routed from the sources to the site at NSMP South. The dense phase pipeline to the Goldeneye export facilities (approximately 1.25km long) would be routed along the east side of the site. This could potentially be run above ground as the pipeline will be located within the fence line of the St Fergus site. Further work is required to assess the impact of constructing this pipeline within the vicinity of the existing NSMP flares.

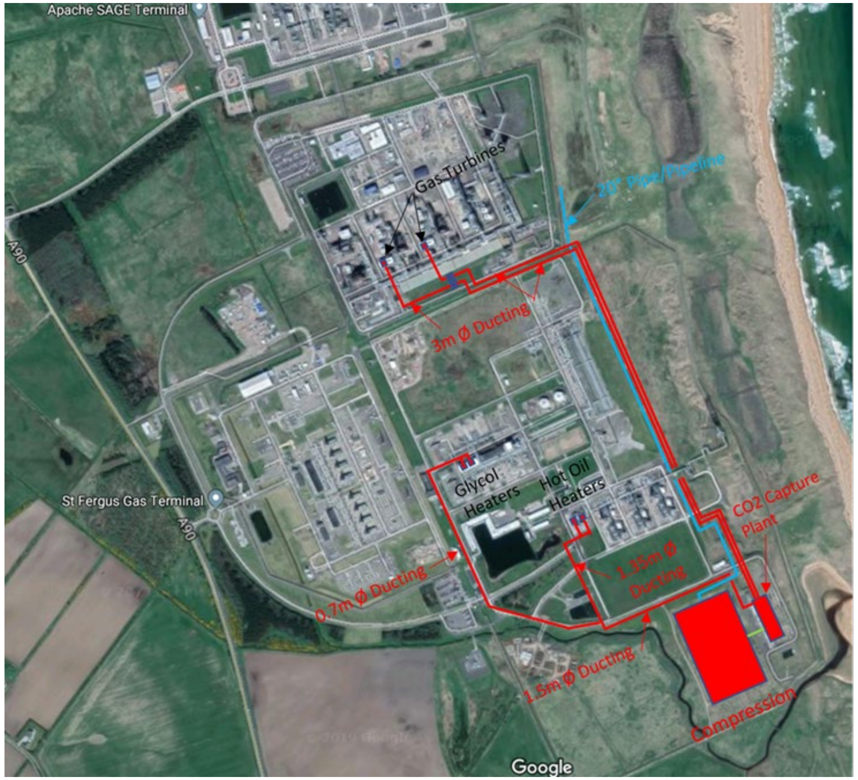

Figure 6-3: Capture and Compression at NSMP South (Image: Google)

Selection of NSMP South would provide potential for build-out opportunities. The area of land located to the west of NSMP South (across the burn) is owned by NSMP and could potentially be used for future expansion of the Acorn CCS plant, although this area is classed as being at risk of flooding.

The NSMP South site is partially impacted by NSMP hazards including flash fire and explosion overpressure. These hazards will need to be considered during the Concept Select phase, to confirm the risk is ALARP.

As with Blackhill, the NSMP South site is located 3.5km south of the Loch of Strathbeg Site of Special Scientific Interest, which is also designated a European Special Protection Area. Direct impacts from construction are unlikely to impact this site, however, there may be an impact on mobile wildfowl (geese, swans) due to disturbance and loss of foraging habitat.

6.2.3 NSMP North Option

The NSMP North site is located on the north side of the NSMP site, adjacent to the boundary line with the SEGAL plant. This site is located in the middle of the SEGAL and NSMP emission sources, presenting an option which would minimise the lengths of required ducting and pipework.

Constructing a new capture, compression, and conditioning plant in the middle of two existing plants will prove more challenging than other site options. NSMP North is impacted by SEGAL and NSMP hazards including jet fires, explosion overpressures and pool fires. Therefore, any plant which is constructed in this area would need to take cognisance of these hazards and demonstrate that the risk is ALARP.

6.2.4 SEGAL Option

Shell has identified a strip of land located on the south side of the SEGAL site which is commercially available. This area is large enough to site the capture plant and blowers for the SEGAL flue gas. This option would have to be combined with another site, on which the compression and conditioning plant would be located.

6.2.5 SEGAL 2600 Option

Unit 2600 is another potential location on the SEGAL site upon which Acorn equipment could be sited. This is a redundant gas processing plant, which would need to be decommissioned and deconstructed to allow Acorn CCS project construction to commence. This existing process equipment is contaminated with H_2S which would need to be removed as part of the decommissioning process.

6.2.6 SEGAL Construction laydown area

This area is located to the north of the SEGAL site and is currently used as a construction laydown area. Shell has indicated that this land could be commercially available for the Acorn CCS project.

6.2.7 Site Split

A subset of the site selection decision is whether the Acorn CCS plant is split between different sites, and where this split would occur. The options are:

- Split between the solvent absorption unit and the solvent regeneration system (stripper column) (explained further in 6.2.8)
- Split between the carbon capture plant and the compression and conditioning plant
- Split between the low-pressure compression/conditioning plant, and the high-pressure compression plant
- No split. The Acorn carbon capture and compression/ conditioning plants are located entirely on one site.

The site selection and the site split decision will be assessed concurrently during Concept Select.

6.2.8 Split between Solvent Absorption and Solvent Regeneration

This option entails locating the solvent absorption column on a different site from the solvent regeneration system. If the solvent absorption column is located local to the flue gas source(s), then this would reduce the required length of flue gas ductwork. Pipework containing the CO_2 rich solvent would be routed from the absorption column to the regeneration system.

Depending on the distances between each emission source there could be a requirement for an absorption column located local to each emission source.

7.0 Process Design Basis Options

7.1 Availability Options

Design availability for Acorn CCS project will be defined during the Concept Select stage.

A reliability, availability and maintainability (RAM) study will be completed to quantify the reliability and availability of the project. The RAM study will form the basis of whether a duty/standby or an alternative arrangement is selected for each element of the plant.

As an example, three of the availability options under consideration are:

- <90%
- 90%
- 95%

Equipment sparing will be specified to achieve this availability. Depending on the equipment, the sparing options are likely to be:

- 1 x 100%
- 2 x 50%
- 3 x 50%
- 2 x 100%
- 2 x 70%

The availability requirement will be dependent to some extent on the commercial agreement for CO_2 storage.

7.2 Minimum Turndown Options

The turndown scenario for Acorn will be defined during Concept Select.

The number of minimum turndown choices will depend on the decision made on the target volume of CO_2 emissions to be captured. The choices will correspond to one or more sources being shut down for maintenance or a trip scenario or changes to the load of the source machine e.g. 100% down to 60% load. The impact on the full chain including the minimum required CO_2 injection flowrate for the Acorn South well, will determine, in part, the decision made.

If the full 345ktCO$_2$/yr is chosen, the minimum turndown options would be:

- 300-330ktCO$_2$/yr; corresponding to capture of one or both of the NSMP sources i.e. glycol furnace and hot oil furnaces
- 190ktCO$_2$/yr; corresponding to capture of the volumes from one SEGAL gas turbine
- 150-180ktCO$_2$/yr; corresponding to capture of the volumes from one SEGAL gas turbine AND one or both of the NSMP sources i.e. glycol furnace and hot oil furnaces
- 40ktCO$_2$/yr; corresponding to capture of the volumes from both SEGAL gas turbines

7.3 Design Life Options

The design life for Acorn CCS project will be defined during the Concept Select phase.

The design life will need to be specified for the capture plant, the compression and conditioning plant, the existing Goldeneye pipeline system, utilities and services and new offshore infrastructure such as subsea flowlines, manifold(s) and well(s). The options are:

- 10 years
- 15 years
- 20 years
- 25 years
- 25+years

Each of the elements may have a different design life, depending on the cost impact, commercial agreements, business case, the risk attitude for build-outs cases.

7.4 CO_2 Compositional Specification

The flue gas and CO_2 composition will need to adhere to strict compositional specifications at multiple points in the process. These points in the process are defined in the block diagram shown in Figure 2-2.

7.4.1 Conform to the Northern Lights and Other UK and European CO_2 Transportation Projects

During an annual meeting (7-11th October 2019), London Protocol Parties, agreed on the adoption of a resolution to allow for the already written, but not formally constituted, amendment to Article 6 of the Protocol to allow sub-seabed geological formations for carbon sequestration projects to be shared across national boundaries. This provides an interim solution to remove the legislative barrier that the London Protocol has presented to the transboundary movement of CO_2.

The Northern Lights CCS project in Norway is progressing which intends to use ship tankers to transport liquid CO_2 from sources near Oslo to a receiving terminal near Bergen. It has the wider goal of accepting CO_2 from elsewhere in Europe.

Acorn build-out assumes CO_2 can be imported and exported via Peterhead to/from other CCS projects, including Northern Lights, and therefore it is likely to be considered an advantage for Acorn CCS project if its CO_2 composition complies with the other CCS project compositional specifications. However, the impact of meeting the other CCS project specifications should be reviewed, as it may incur heavy costs or negatively impact the Acorn CCS project infrastructure.

The decision to comply or not comply will be made for each component and compared to alternatives.

7.4.2 H_2O Specification

Moisture level is critical to integrity management of CO_2 pipelines and safe transport as CO_2 dissolves in free water to produce corrosive carbonic acid. Carbon steel pipelines are commonly employed for CO_2 transport, which offer minimal corrosion resistance. As such, operating conditions are maintained to prevent the formation of a free water phase, but in the event of a depressurisation scenario, this can occur at high moisture levels. Additionally, dry conditions are required to prevent hydrate formation in downstream equipment and subsea pipework. The export specifications considered for water are:

- 30ppmv
- 50ppmv
- >50ppmv

30ppmv is the specification used for the Northern Lights CCS project.

50ppmv is the design specification been used for other UK CCS projects, including Peterhead and White Rose and is the transport specification for the Snohvit offshore CO_2 pipeline which has been operating since 2008 (DNVGL, 2017). 50ppmv is considered full dehydration, with no free water present in CO_2, and <60% of the saturation concentration. At concentrations higher than 50ppmv, there is a risk that under certain process conditions, liquid water may form in the pipeline, resulting in corrosion.

7.4.3 O_2 Specification

O_2 removal from export CO_2 may be necessary to minimise pitting corrosion within well tubing. Two export specifications for O_2 have been considered:

- 5ppmv
- 10ppmv

10ppmv was selected for the White Rose and Northern Lights CCS projects, to avoid chloride stress corrosion cracking in the lower well tubing where CO_2 mixes with saline water.

5ppmv was used for the Peterhead CCS project, to specifically avoid exceeding 10ppbv O_2 (parts per billion volume) in the well formation water in the existing wells.

7.4.4 SO_X and NO_X Specifications

Oxides of sulphur and nitrogen (SO_X and NO_X) also dissolve in free water to form acids. They also promote the drop out of a water phase from the CO_2 product and are highly toxic and therefore pose an additional safety consideration. If required, based on confirmation from technology vendor, removal of SO_X and NO_X would take place before the solvent capture process as SO_X can degrade the solvents used in the degradation process.

- 10ppmv each
- 100ppmv each

The Northern Lights Project specifies a concentration of 10ppmv whereas other projects such as White Rose have a more relaxed value of 100ppmv.

The expected level of these contaminants in the flue gases fall well below the suggested specifications. Again, monitoring of the flue gases will be required to ensure that this does not change, e.g. due to changing composition of the fuel gas.

7.4.5 Residual Solvent Specification

Trace solvents used in the capture process may be present in the CO_2 product stream. In the Northern Lights project, a value of 10ppmv is specified for amines or ammonia. This is expected to be readily achievable without changes to the process flow scheme but will be reviewed once the capture technology has been selected. No motivation for specifying a lower concentration than 10ppmv has been identified.

7.4.6 Hydrogen specification

Whilst hydrogen will not be present in the CO_2 produced from St Fergus flue gases, the residual hydrogen within CO_2 product streams from the Acorn Hydrogen project may need to be considered in the material selection made for subsea and wells infrastructure.

Hydrogen presence significantly enlarges the two-phase region of the CO_2 phase diagram, even at low concentrations. Hydrogen embrittlement may also occur in a two phase scenario, where hydrogen will split almost entirely into the gaseous phase, and this needs to be considered.

7.4.7 Hydrogen sulphide specification

H_2S will not be present at appreciable levels in the flue gases from St Fergus due to the oxidising environment of the combustion sources. However, it may be present in CO_2 streams from hydrogen generation so needs to be taken into consideration, particularly for the material selection of the well tubing. When dissolved in free water H_2S can cause pitting corrosion of corrosion resistant alloys. H_2S can also poison O_2 removal catalysts so separation must occur before this unit and this may affect the location of future tie-ins.

7.4.8 CO Specification

Carbon monoxide (CO) is a toxic component which may be present in a number of sources of CO_2. However, it is not expected to be present at higher levels than in the Northern Lights specification, 100ppmv, according to compositional sampling data. However, monitoring of flue gases will be necessary to ensure that this does not change, e.g. due to operating changes in furnaces/turbines.

Whilst it may be present in streams from hydrogen production it will not affect the material choices made in subsea infrastructure and in the well.

7.4.9 Other components

Several other component specifications have been identified in other CCS projects, e.g. aldehydes, heavy metals. However, these are unlikely to alter the process flow scheme of the Acorn CCS plant in Phase 1. They will be reviewed during the Define phase of the project.

8.0 Carbon Capture Plant Options

Phase 1 of the Acorn CCS project is limited to the capture of CO_2 from existing post combustion sources at St Fergus.

Up to 345ktCO_2/yr of post combustion CO_2 is expected to be collected from flue gases at temperatures above 200°C and at near atmospheric pressure from natural gas fired equipment.

The expectation is that the collection and subsequent capture of CO_2 will not adversely affect the performance of the source equipment, nor will it require extensive modifications. Heat integration will be considered.

The time frame for the Acorn CCS project is to be operational in the early to mid-2020's, therefore only technologies that can meet this time frame have been considered.

8.1 Technology

The choice of carbon capture technology is driven to a large extent by the priority to minimise schedule risks and meet the 2024 first injection date, in accordance with project value drivers. For this reason, the usage of a liquid solvent technology was recognised as a given.

A basic overview of the liquid solvent absorption process is shown in Figure 8-1. It begins with the CO_2-containing flue gas being fed to the bottom of an absorber column where it is contacted by descending liquid solvent in a counter-current manner. The solvent binds to the CO_2 and the concentration of CO_2 in the gas phase is progressively decreased as it rises through the column. The treated gas leaves the top of the column and is vented to the atmosphere.

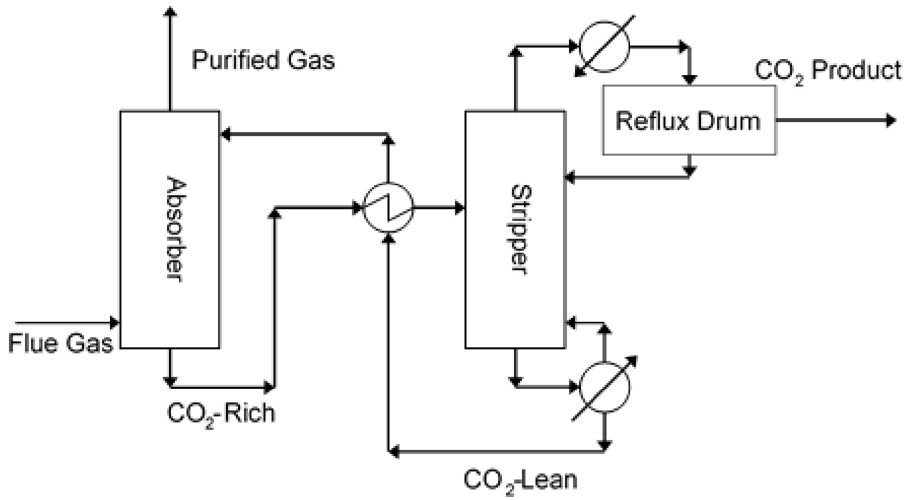

Figure 8-1: Simplified Absorber Flow Chart

The liquid solvent options are:

- Amine processes
- Chilled Ammonia Process
- Hot potassium carbonate processes
- Carboxylic acid process
- Physical solvent processes

8.1.1 Amine processes

Amine based solvent absorption is the industry standard technology for CO_2 capture. Primary, secondary and sterically hindered amines are blended with various inhibitors to prevent solvent degradation, corrosion or foaming. 1st generation processes typically used mono ethylene amine (MEA), although more advanced solvent systems have been employed which improve CO_2 absorption capacity, whilst reducing degradation rates.

The process flow scheme follows that shown in Figure 8-1, although commercial offerings have considerable optimisation. The absorber column typically operates at around 50°C, whereas the absorber operates at a higher temperature of 110-120°C. The mechanism is therefore temperature-swing, dependent on the capture and release properties of the solvent.

8.1.2 Chilled Ammonia Process

Ammonia is an alternative solvent to amines but poses difficulties in absorption processes due to its volatility. This was overcome by Alstom (now General Electric) who developed the Chilled Ammonia Process (CAP) comprising a low temperature, chemical absorption operating between 5-15°C, with the stripper still operated at around ~150°C. The basic chemistry and process is similar to amines with CO_2 bonding to ammonium carbonate to form ammonium bicarbonate in the absorber column.

8.1.3 Hot potassium carbonate processes

Similar to the amine processes, the potassium carbonate (K_2CO_3) absorption process follows a similar flow scheme to the one shown in Figure 8-1, however, regeneration of the solvent is achieved through pressure reduction, with both columns typically operating at high temperatures in the range of 100°C-116°C.

8.1.4 Carboxylic acid process

C-Capture, a spin-off company from the University of Leeds, have developed a chemical absorption process where amines are replaced with a carboxylic acid solvent. The absorber and stripper columns operate at similar temperature to amine processes (20-30 °C and 100-120 °C respectively) however, it has potentially lower energy requirements for separation.

8.1.5 Physical solvent processes

Where the chemical absorption processes discussed above involve the formation of chemical bonds, physical absorption relies on the solubility properties of the target molecule within the solvent. Despite the different underlying mechanism, the overall process is similar. However, instead of employing temperature swing, a pressure-swing approach is generally taken. A higher pressure absorber is paired to a low pressure stripper. In the simplest case, the stripper is replaced with a flash drum.

8.2 Capture Technology Supplier

The capture technology supply chain will be engaged during the Concept Select phase to shortlist based on technical and commercial suitability but this decision will not be made until just after Define phase begins due to the longer term commercial impacts associated with the choice of technology supplier.

8.3 Capture Plant Recovery Specification

It is expected that the majority of the commercial capture technologies will be capable of achieving a CO_2 recovery of 90% from the flue gas stream. During the capture technology and vendor selection process, the recovery rate will be reviewed. The recovery rate will be evaluated against increased capex, due to increased column height, and increased opex, due to higher energy requirements. The options are:

- Low recovery: 85%

- Base case: 90%
- High recovery: 95%

8.4 Pre-Conditioning of Flue Gas Options

8.4.1 Requirement for SO_X/NOx removal

SO_X and NO_X are not anticipated to be problematic components for any of the capture processes reviewed, particularly at the low levels of the St Fergus CO_2 sources, however there may be a requirement to remove these components as more detail is obtained.

In addition, some degree of SO_X and NO_X removal is achieved through the use of direct contact coolers which are proposed for the base-case solvent absorption system.

The options are:

- Required to meet vendor requirements
- Required to meet CO_2 compositional specification
- Not required to meet vendor requirements or CO_2 compositional specification

8.5 Heat and Cooling Integration

All of the CO_2 capture technologies considered have a significant heating and cooling requirement. The duties used here have been assumed from initial work with a carbon capture technology supplier for the capture of 345ktCO_2/yr.

These values will be challenged and refined in the Concept Select phase and into the Define phase during the carbon capture supplier engagement and tender process.

8.6 Cooling Options

Cooling is a crucial utility for the Acorn process and is potentially required for the following applications:

- Flue gas cooling upstream of the capture plant
- CO_2 absorber water wash
- Liquid solvent regeneration system
- LP compression
- HP compression
- Export chiller package (CO_2 cooling)

As a basis for developing the options, the cooling demand has been estimated for each of these potential applications. It should be noted that these are preliminary figures, based on a CO_2 throughput of 345ktCO_2/yr, and are subject to change. Table 8-1 presents this information:

User	Cooling Thermal Duty	Source
Flue gas cooling	40 MW	PBDE Calculation
Capture plant (DCC, CO_2 absorber liquid solvent regeneration)	60 MW	Acorn CO_2 SAPLING Transport Infrastructure Project (Genesis 2019)
LP compression[1]	3.2 MW	
Dehydration[1]	1.2 MW	
HP compression[1]	3.1 MW	
Export chiller package[1]	3.1 MW	

Table 8-1: Acorn Preliminary Cooling Duties

Note 1 – These results were prorated to a flowrate of 0.34MtCO_2/yr, as the Acorn CO_2 SAPLING Transport Infrastructure Project was based on a flowrate of 0.55MtCO_2/yr (as it assumed capture volumes from the Phase 2 hydrogen production as well). The thermal duties should be considered approximate results, subject to change.

Flue gas cooling assumes use of the existing WHRU on each SEGAL turbine, which reduces the additional cooling duty required. This would be a change from the current infrequent and intermittent use of the WHRUs for regeneration of molecular sieve beds at SEGAL.

The capture plant cooling duty is based on the required cooling water flowrate provided for the carbon capture plant. The quoted cooling water flowrate was converted into a cooling duty, based on a temperature difference of 8°C.

In addition, compression will have an additional intercooler cooling duty and CO_2 entering the Goldeneye pipeline needs to have a temperature of ≤25°C to protect the Goldeneye pipeline from running ductile fracture.

During the Concept Select phase, a holistic approach will be adopted, for considering all of the heating and cooling requirements for the full Acorn facilities. A heat integration study will be completed, which considers all the process streams which require heating and cooling, ensuring the heat loads are balanced.

Various technology options will be considered for the provision of cooling:

- WHRU
- Seawater cooling
- Air cooling
- Cooling tower
- Chiller package (export cooling only)
- Direct Contact Cooler (DCC) (required to cool and condition flue gas stream prior to entry to Carbon Capture plant)

8.6.1 WHRU Options

An existing WHRU is installed on the exhaust stack of each SEGAL gas turbine. This system recovers waste heat from the SEGAL flue gas by heating oil which is used on the SEGAL plant. This system is used infrequently, hence, there is the potential to utilise this source of cooling/heating for Acorn.

SEGAL flue gas will be at a temperature of approx. 500°C, whilst NSMP flue gas will be at a temperature of approx. 200°C. The flue gas will require cooling down to around 100°C for entry into the capture plant.

Initial calculations have shown that the WHRU does not have sufficient capacity to cool the SEGAL flue gas down to the temperature required for the capture plant. Therefore, an additional source of cooling will be required. Two options which will be considered include modification of the existing WHRU to provide additional cooling, and installation of an additional WHRU to cool the flue gas to the required temperature. Depending on the emission sources which are selected, a new WHRU will either be sized for SEGAL flue gas alone or SEGAL and NSMP. Sizing calculations will consider heat loss which occurs through the ductwork to the atmosphere.

8.6.2 Air Cooling Option

Fin fan air coolers can be used to cool the process streams. Process fluid flows through tubes within the body of the cooler. Motor driven centrifugal fans blow air across the process fluid, resulting in cooling of the fluid via conductive and convective heat transfer.

8.6.3 Seawater Cooling Option

Seawater cooling involves pumping a feed of water from the sea around a once-through process cooling circuit, then discharging the warm water back to sea. Heat would be transferred from the process streams to seawater using heat exchangers. This seawater system would consist of a pipeline running from the beach to the Acorn CCS plant, seawater pumps, inlet filtration and biocide injection.

There is no known existing seawater cooling system at St Fergus.

8.6.4 Cooling Tower Options

Two key types of cooling tower options which will be considered are:

- Dry closed circuit
- Wet open circuit

A cooling tower would be combined with a cooling water circuit and heat exchangers for transfer of heat from the process.

A dry closed-circuit system (Figure 8-2) consists of a cooling tower in which heat is transferred from the working fluid (water) to ambient air, via tube bundles. This type of system does not utilise evaporative heat transfer and there is no direct contact between the working fluid and air.

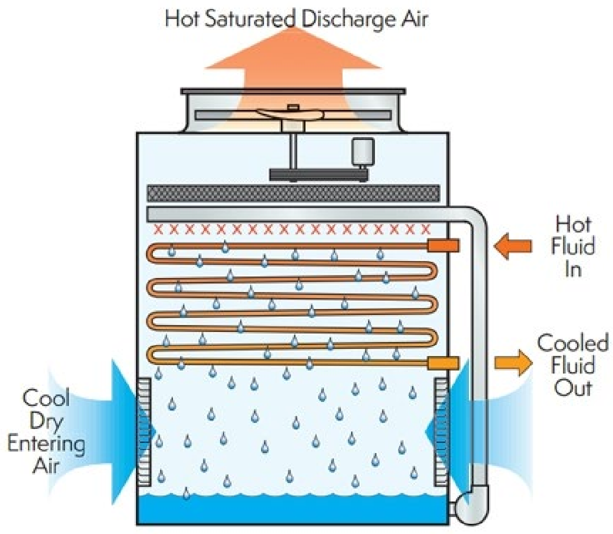

Figure 8-2: Closed Circuit Cooling Tower Diagram (Konukisi, 2019)

A wet open circuit system (Figure 8-3) consists of a cooling tower in which evaporative cooling is used to transfer heat. The cooling fluid and the fluid which evaporates are the same – water. Hot water flows downwards through structured packing and contacts cool, dry air entering via the bottom of the packing. A proportion of the water evaporates, resulting in cooling of the hot water, which falls to the bottom of the packing and collects in a basin. The warm, saturated air exits to atmosphere via the top of the cooling tower. This type of system would require a regular top-up off water to replace evaporative losses.

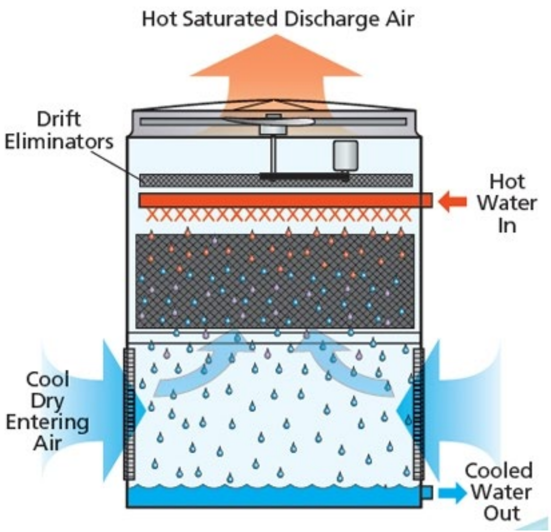

Figure 8-3: Wet Open Circuit Cooling Tower Diagram (Konukisi, 2019)

8.7 Heating Options

Heating is potentially required for the following applications:

- Regeneration of liquid solvent
- Intermittent use in solvent recovery system
- Regeneration of molecular sieves

As a basis for developing the options, the heating demand has been estimated and is shown in Table 8-2

User	Heating Thermal Duty
Liquid solvent regeneration	42MW
Molecular sieve regeneration	0.9MW

Table 8-2: Acorn Preliminary Heating Duties

The different options which are available for heat provision are:

- WHRU
- Gas fired heaters
- Electric heaters.

8.7.1 Use of WHRU

The heat recovered from the flue gas stream could be used to regenerate the liquid solvent. Table 8-1 shows that the cooling duty for the flue gas is approximately equal to the heating duty required for the liquid solvent. (40MW vs. 42MW). The practicalities of recovering all of this heat for solvent regeneration will be considered during the Concept Select phase.

8.7.2 Gas Fired Heater Options

A gas fired heater can be used to generate either LP steam or hot oil to regenerate the liquid solvent. Gas fired heaters are widely used across industrial sites and are already used on both the SEGAL and NSMP sites.

As a gas fired heater combusts natural gas to generate heat, this would introduce a new source of CO_2 emissions on site. Based on the required heating duty, initial indications are that the CO_2 emissions from such a heater would exceed the volumes produced by the NSMP hot oil and glycol heaters. One of the key aims of Acorn is to decarbonise operations at St Fergus, therefore, increasing CO_2 emissions by installing a gas fired heater is not desirable.

8.7.3 Electric Heating Options

Generation of steam/hot oil using an electric boiler is a viable technology offered by many manufacturers. Selection of such a solution would eliminate the issue of CO_2 production which exists with a gas fired heater, although there would still be CO_2 emissions associated with grid electricity production.

The key challenge with electrical heating is that it is typically two to three times more expensive than heat generation using natural gas, as the thermodynamic efficiency of power generation is lower than that of a gas fired heater

Selection of electric heating would significantly increase the power consumption of Acorn CCS project, as highlighted by the figures given in Table 8-2. This will impact the electrical infrastructure required on site.

An initial review of vendor material has suggested that it will not be feasible to provide a standalone immersion heater with sufficient capacity to regenerate the liquid solvent. However, a standalone electric boiler generating steam/hot oil is considered a viable solution, offered by vendors such as Parat and Exheat.

8.8 Heating Medium Options

The following mediums options will be considered for the provision of heat:

- Hot Oil
- Steam

8.8.1 Hot oil

Hot oil is an existing utility system available on both the SEGAL and NSMP sites. Hence, there is an opportunity to integrate into an existing hot oil system. Hot oil offers several advantages including:

- No freezing issues during low ambient temperatures
- Fewer corrosion issues than a steam system
- Hot oil systems do not need to be pressurised to the same extent, presenting lower risk to operators in the event of a leakage
- Integration of existing SEGAL WHRU into the Acorn design

8.8.2 Steam

Steam is commonly used across onshore industrial sites for the provision of heat. Steam is attractive as a heat transfer fluid due to its high latent heat, resulting in delivery of a high rate of heat transfer. From a safety perspective, pressurised steam presents a higher risk to personnel. If a leak occurs, then steam condenses on contact with skin, resulting in severe burns.

8.9 Waste Management Options

The main effluent streams produced by Acorn CCS project onshore plant come from:

- Direct contact cooler (DCC) waste water
- Solvent regeneration waste stream
- Liquid solvent absorber flue gas
- Process drains

Due to the differences in each of the effluent stream, each stream will have different options for dealing with the waste.

Whilst the decision on effluent treatment is not explicitly required at this stage, the impact on the amount of land required for onsite treatment, does need to be taken into account in the site location decision.

8.9.1 DCC Waste Water Options

During operation, the water within the DCC cooling loop will absorb small quantities of NO_X/SO_X present in the flue gas stream. This will reduce the pH of the water. Therefore, a bleed of water will need to be removed from the system and replaced with fresh demineralised water.

The flowrate of this bleed stream will depend on the emission sources which are selected and the DCC sizing. However, based on a CO_2 throughput of 345ktCO_2/yr, the bleed flowrate would be approximately 2,390kg/hr.

To treat this weakly acidic wastewater stream, the options which will be considered are:

- Tie-in directly to one of the existing wastewater systems at St Fergus
- Tie-in to a new Acorn wastewater system
- Requirement for chemical neutralisation
- Collect and transport offsite for treatment

8.9.2 Solvent Reclaimer Waste Management Options

During operation, the liquid solvent will slowly degrade to form heat stable salts (HSS). Although a proportion of these can be converted back into liquid solvent, some remain in the solvent reclaimer system. Raw water will be added to these residual solids, before being withdrawn as hazardous waste.

The options which will be considered for treating this waste stream are:

- Treatment onsite then transport offsite for disposal
- Transport offsite without onsite treatment

8.9.3 Liquid Solvent Absorber Vent Gas Options

A depleted CO_2 lean flue gas stream will be emitted from the absorption column. The flue gas will pass through several stages of water wash within the liquid solvent column prior to discharge, minimising the carryover of solvent. The depleted flue gas will be emitted directly to the atmosphere.

The flowrate of the depleted flue gas will depend on the emission sources which are selected. However, based on an emissions volume of 345ktCO_2/yr, the vent gas flowrate would be approximately 447,405Nm^3/hr.

The options for dealing with the emissions are:

- Vent directly to atmosphere
- Scrubbing

8.10 Demineralised water make-up

Demineralised water is required as a feed to the DCC and for solvent make-up within the carbon capture plant. It will also be required for boiler water if steam is selected as the heating medium. The options available for the provision of this utility are:

- Provision of a new demineralised water generation system
- Supply of a new demineralised water via tote tanks

- Tie-in to an existing system, if available.

9.0 Compression and Conditioning Options

9.1 Compression Technology Options

Compression is required to deliver CO_2 offshore from the CO_2 capture plant to the pressure required for injection into the Acorn reservoir.

The CO_2 from the capture plant is low pressure (up to 1barg) and in gaseous phase, whilst the CO_2 entering the Goldeneye pipeline is in dense phase between 80barg (minimum dense phase pressure of CO_2 at the 25°C assumed necessary to reduce running ductile fracture risk), and 120barg (based on Goldeneye maximum working pressure).

9.2 Low Pressure Compressor Technology Options

There are a number of low pressure compression technology options for taking near atmospheric pressure gaseous phase CO_2 to the conditioning pressure. Compression of the CO_2 generally requires more stages of compression, compared to other fluids, due to the large molecule size and a requirement to avoid sonic velocities within the compressor.

Technology options are:

- Integrally geared centrifugal compressor
- Reciprocating compressors
- Multi-stage centrifugal compressor
- Screw compressor
- Ramgen supersonic compressor

9.2.1 Integrally geared centrifugal compressor

The integrally geared centrifugal compressor is a design that incorporates a multi-shaft compressor in which each compression stage has a 3D impeller, optimised for the compression stage, operated at its optimum speed. The compressor utilises a gear unit with central bull gear and different gear pinions, allowing the unit to drive multiple impeller stages.

All the compression, LP and HP, can be achieved with a single machine where up to 8 stages are possible, and there are numerous references for integrally geared compression in CO_2 compression service globally.

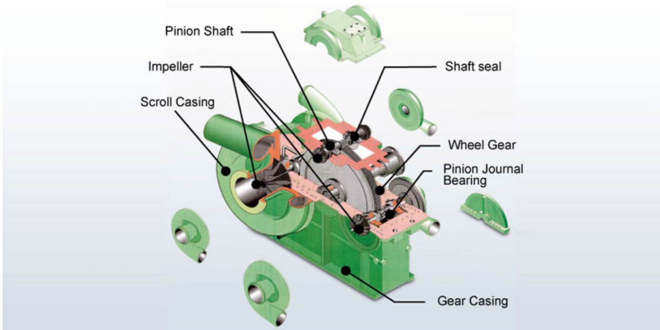

Figure 9-19-: Example of an Integrally Geared Compressor (Mitsubishi Heavy Industries Group, 2019)

9.2.2 Reciprocating Compressor

A reciprocating compressor is a positive displacement machine that utilises a piston to compress the gas. They can have an efficiency as high as 97%. However, the volume flow required on the LP compression is beyond the referenced limits of the reciprocating compressor so would require multiple large machines to achieve the duty.

9.2.3 Multi-stage Centrifugal Compressor

Centrifugal compressors achieve a pressure increase by increasing the velocity of the gas through the compressor, utilising a series of rotors or impellers, and converting the energy into potential energy by slowing the gas again in the diffuser.

9.2.4 Screw Compressor

A screw compressor is a type of rotary compressor that uses two helical rotors within a housing that trap and compress the working fluid as it passes through the machine. As the rotors turn the volume available to the working gas reduces increasing pressure.

9.2.5 Ramgen Supersonic Compressor

Supersonic compression technology is being developed by Dresser-Rand. The technology consists of a rotating wheel that utilises sonic shocks to compress the CO_2 resulting in much larger pressure ratios being achievable. While a very promising technology it is currently under development with initial testing having been completed recently.

9.3 Turndown Options

There are a number of technology options for turning down the throughput of both the LP and HP compressors. Of the options below, not all are applicable to all of the compressors types listed, but indicate options which may be reviewed. The options are:

- Variable inlet guide vanes
- Suction throttling
- Variable speed drive
- Recycle

9.4 Conditioning Options

Conditioning of the CO_2 is required to deliver CO_2 at the specification required for offshore transport.

9.4.1 O_2 Removal Options

The following technologies exist for O_2 removal:

- Catalytic oxidation
- Chemical scavenging
- Physical removal from dry CO_2
- Physical removal from rich solvent

9.4.1.1 Catalytic O_2 Removal Option

Catalytic O_2 removal uses an oxidation reaction to convert O_2 to H_2O. This takes place in a reactor filled with a catalyst bed (CATOX reactor). Hot (150°C) CO_2 is mixed with hydrogen at the vessel inlet. This gaseous mixture passes over the catalyst bed, which drives the exothermic oxidation reaction, converting O_2 and H_2O to water. Water is then removed downstream within the dehydration stage.

Although hydrogen will be injected into the CO_2 stream, this will not affect the export specification for hydrogen, as the volumes are small relative to the total CO_2 flowrate, and the majority of hydrogen will be converted into H_2O. The hydrogen left in the CO_2 will be confirmed in the Concept Select phase.

9.4.1.2 Chemical Scavenging Option

Chemical scavenging removes oxygen via a reagent such as hydrazine or sodium sulphite. Such reagents are expensive and in the case of hydrazine, are carcinogenic.

9.4.1.3 Physical Removal from Dry CO_2 Option

This option involves removal of oxygen by liquefying then distilling the CO_2 stream downstream of the dehydration unit. This option would require significant additional equipment compared to catalytic O_2 removal.

9.4.1.4 Physical Removal from Rich Liquid Solvent Option

This option involves removing oxygen from the rich solvent between the CO_2 absorption column and regenerator. This could be achieved by either flashing the rich solvent or via a stripping reaction.

9.4.2 Moisture Removal Technology Options

The key technologies which were considered for removal of moisture include:

- Liquid desiccant (TEG absorption)
- Solid desiccant (molecular sieve)
- Low temperature separation
- Supersonic separation
- Membranes

9.4.2.1 TEG Absorption Option

Tri-ethylene glycol (TEG) is an aqueous based chemical which has an affinity for water. Hence, it can be used to absorb water from a gas stream in a process known as TEG absorption. This process is normally carried out in a vertical vessel known as a TEG Contactor. CO_2 enters the column and flows upwards through a packed bed. Lean TEG is injected at the top of the column and flows downwards through the packed bed contacting the CO_2 stream. The packed bed provides a large surface area for contact of the two phases, and the lean TEG absorbs any water molecules. The water rich TEG then falls to the bottom of the vessel and passes to a regeneration system, in which water is boiled off and the TEG is regenerated, ready for re-use.

9.4.2.2 Molecular Sieve Option

Molecular sieve technology consists of a duty/standby vessel filled with a porous, highly adsorbent material. The wet gas stream flows through the duty vessel, with water molecules and other contaminants absorbed within the pores of the material. Once the vessel is saturated with water, the process switches to the standby vessel, and the saturated vessel can be regenerated. Regeneration can be carried out by heating the vessel, purging with another gas stream or via pressure swing.

9.4.2.3 Low Temperature Separation Option

This technology cools the CO_2 stream to below its water dewpoint, condensing the water vapour. This water can then be separated out within a downstream separation vessel, producing a dry gas stream.

Cooling can be achieved using either a closed loop refrigeration system, or an internal refrigeration system which utilises the process fluid as a refrigerant.

9.4.2.4 Supersonic Separation Option

Supersonic separation is a relatively novel technology which can be used to separate out heavy components, such as water, from a gas stream. The technology consists of a device provided in tubular form and is normally designed with flanged end connections to connect to pipework. The device works by inducing a swirling motion in the CO_2 stream, then increasing the velocity of the stream via a restriction, resulting in a pressure drop and condensation of water droplets. Water then separates out via the influence of centrifugal force.

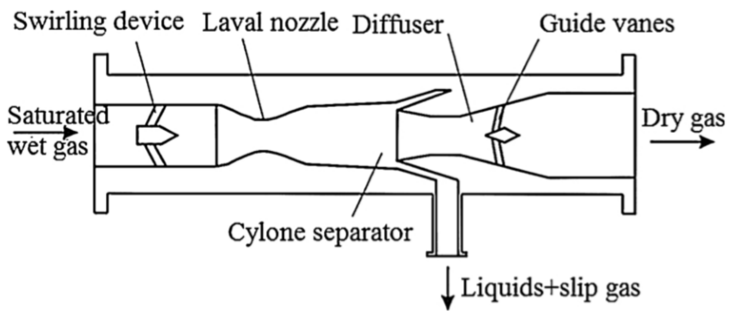

Figure 9-2: Diagram of Supersonic Separator (Cao & Bian, 2019)

9.4.2.5 Membranes Option

Membrane technology involves passing a high-pressure CO_2 stream over a semi-permeable gas membrane. The highly permeable components (water) pass through the membrane to the low pressure permeate side, reducing the water content of the CO_2 stream. Membrane technology can achieve water concentrations in the range 80-150ppmv, which is greater than the Acorn export specification.

9.5 Conditioning Pressure Options

Selection of a conditioning pressure is based on the cost analysis of the options and on build out options for the plant. LP compression would be specified to deliver a pressure after which the CO_2 would be conditioned. Conditioning would be followed by HP compression to the export pipeline inlet pressure. There are different options for the pressure at which the CO_2 is conditioned:

- 20barg
- 25barg
- 30barg

9.6 High Pressure Compressor Options

There are a number of technology options for the gas to dense phase compression of compression of CO_2.

- Integrally geared centrifugal compressor
- Multi-stage centrifugal compressor
- Ramgen supersonic compressor
- These technologies are discussed in section 9.2.

9.7 Export Pipeline Inlet Pressure Options

The selection of the pipeline inlet operating pressure (compressor outlet pressure) will be dictated by the required tubing head pressure across the life of the field and the flow assurance (steady state and transient) and will dictate the output pressure of the compressor.

In order to remain in single (dense) phase flow regime, this will be constrained by the saturation line of CO_2, which at 25°C (see Section 9.8) is approximately 80barg.

At the top end, this will be constrained by the design pressure of the Goldeneye pipeline (132barg).

The initial flow assurance work found that the pressure in the pipeline at low flow rates was dictated by the hydrostatic pressure gain, due to the elevation drop between the pipeline inlet and the subsea wells, resulting in an increase of 10barg over the length of the pipeline. By contrast, at a throughput of $4MtCO_2/yr$

the higher flowrate results in a net pressure drop, due to frictional losses, of less than 4barg.

The options for the pipeline inlet operating pressure will be approximately:

- 90barg
- 100barg
- 110barg

9.8 Chiller Package Option

To avoid ductile fracture in the pipeline, the export temperature must be below 30°C. A temperature specification at 25°C was chosen in the Acorn CO_2 SAPLING Transport Infrastructure Project. As air cooling is restricted by ambient temperature, particularly during summer months, an additional stage of export cooling is envisaged via a chiller package. This will be provided via a liquid refrigerant loop.

The refrigerant package would only be intended for intermittent operation, when the ambient air temperature is insufficient to achieve an export temperature of 25°C.

The options for chiller refrigerants are:

- Propane
- CO_2 slipstream
- R134A
- Ammonia
- Isobutane

If another cooling technology is selected for the capture plant which can achieve below 25°C consistently (e.g. cooling tower), then this would eliminate the requirement for a chiller package on CO_2 export.

9.9 Metering Technology Options

The metering specification is based on the Tier 3 metering classification within the European Union (EU) Emission Trading Scheme (ETS) regulations. This requires an accuracy by mass of ±2.5%

For quantities of CO_2 transferred from one installation to another, the Tier 4 metering classification may be required, which is ±1.5%, unless it is not considered technically feasible or would incur an unreasonable cost.

In addition, the injected CO_2 will need to be measured for reservoir performance monitoring.

As part of the metering philosophy defined in Concept Select phase the metering locations, specification and technology will need to be specified.

9.9.1 Metering Locations

There are potentially several locations where metering to either Tier 3 or Tier 4 may be required. These include:

- Flue gas measurement upstream of the capture plant
- Flue gas at the capture plant emissions vent
- CO_2 gas measurement between the capture and compression plants
- Compression & conditioning plant vent
- CO_2 dense phase measurement after the compression and conditioning plant

- CO_2 dense phase measurement at the well

Additional consideration, in the form of straight lengths and/or spools, may be given to the future build-out options and the metering required for these tie-in locations.

9.9.2 Flue Gas and CO_2 Gas Phase Metering Options

Flue gas metering is required for measuring the flowrate of each flue gas stream and gas phase CO_2 metering of the captured CO_2. This application is governed by pressure drop limitation, as the flue gas and gas phase CO_2 sources are at near atmospheric pressure.

Monitoring of the flue gas composition will also be required.

The options are:

- Ultrasonic
- Thermal insertion probe

9.9.2.1 Ultrasonic Option

An ultrasonic flowmeter utilises ultrasound to measure the velocity of a fluid and calculate the volumetric flowrate. The flowmeter utilises a transducer to send a beam of ultrasound from one side of the pipe to the other at an angle. A transducer at the other side of the pipe receives the signal. The transit time of the signal is calculated in the same direction as flow and against the direction of flow. This difference is then used to calculate the average fluid velocity, which in turn is converted to a volumetric flowrate.

9.9.2.2 Thermal Insertion probe Option

A thermal probe is inserted in the fluid medium and utilises a sensor which is heated to a specific temperature, greater than the fluid to be measured. The fluid conducts heat from the sensor in proportion to its mass flowrate, permitting the flowrate to be calculated.

9.9.3 CO_2 Dense Phase Metering Options

Dense phase CO_2 metering is required for measuring the CO_2 export flowrate from St Fergus via the Goldeneye pipeline. Dense phase flow measurement for CO_2 is relatively novel and not well established, and whilst orifice plate metering is suitable for the application, due to the elevated pressure drop created by the orifice plate, there may be a risk of CO_2 phase change.

The options that are considered suitable, although some may require additional qualification, are:

- Coriolis
- Ultrasonic
- Orifice plate

9.9.3.1 Coriolis Option

This metering technology utilises the Coriolis effect generated by a fluid flowing through a narrow tube, to measure the mass flowrate of the fluid.

9.9.3.2 Ultrasonic Option

Ultrasonic metering for this application is considered to be at an experimental level only. Field testing with a clamp-on meter would be required before suppliers would recommend the use of ultrasonic technology. The low viscosity of CO_2 also presents a challenge to ultrasonic meters

9.9.3.3 Orifice Plate Option

Orifice plates measure the pressure drop across a restriction in flow and uses this information to calculate a mass or volumetric flowrate.

9.9.4 Compositional Monitoring Options

Monitoring of the flue gas composition and CO_2 composition is also likely to be required at the locations identified in the block diagram (Figure 2-2). This can be either:

- Continuous emissions monitoring system (CEMS)
- Discrete samples

10.0 Power, Metering and Control Integration Options

10.1 Power Options

The preliminary power requirements for Acorn CCS project have been estimated and are presented in Table 10-1. Note that these figures are based on a CO_2 throughput of 345ktCO_2/yr, and hence, are subject to change during the Concept Select phase.

Initial indications are that this load cannot be supplied from either SEGAL or NSMP. Therefore, Acorn CCS project will require a separate power connection to the national grid. Study work is currently ongoing to assess the infrastructure required for such a connection.

User	Power Requirement
Flue Gas Blowers	5 MW
Capture Plant Ancillaries	2 MW
Capture Plant Cooling[1]	1.4 MW
Capture Plant Heating[2]	-
Compression & Conditioning	5.4 MW
Total	13.8 MW

Table 10-1: Preliminary Power Requirements for Acorn

[1]Cooling power requirement based on fin fan air coolers

[2]Heating power requirement based on assumption that heat duty for solvent regeneration can be recovered from the flue gas using new WHRU. This assumption will be assessed during the heating/cooling study.

The options for supplying power to Acorn CCS project are:

- New connection to the national power grid
- New gas fired power generation onsite, complete with CCS
- Organic Rankine cycle (ORC)
- Local renewable power

As with the other options, the extent to which the build-out cases are taken into account in the power provision will need to be justified.

10.1.1.1 Organic Rankine Cycle (OCR)

It is possible to recover waste heat and convert the energy to power using an ORC. In this system, a low boiling point, organic liquid is evaporated using a waste heat stream and passed through an expansion device, e.g. a turbine, to provide mechanical energy. The gas is then condensed using an incoming cold stream before being pumped back to the evaporator.

It is a technology to be considered when assessing the wider heating and cooling requirements of the plant and whether enough waste heat is available to justify its application.

10.2 Control Integration Options

The Acorn CCS project will need a control room to control the flue gas collection equipment (blowers, dampers), CO_2 capture plant, compression and conditioning plant, and the offshore well. The facilities required are likely to include:

- Onshore plant control
- Master control station (MCS) for the offshore equipment (tree and well)
- Emergency shutdown capability (Including emergency depressurisation or equivalent)
- Fire and CO_2 monitoring
- Metering
- Emergency response provision
- Communication links to the flue gas source plant
- Interfaces to the host site shutdown system

The existing control rooms at SEGAL/NSMP would need to be modified with a remote connection to the Acorn CCS plant process control and shutdown system to allow for precise control and to allow emergencies to be managed.

The options under consideration for control room location are:

- Installation of a new Acorn specific control room on the Acorn CCS plant site
- Modifying the SEGAL or NSMP control room to also control the Acorn CCS project equipment (this is based on the capture of flue gas from these sites and the requirement for a tie-in with these systems regardless)
- Re-purposing the former Miller control room on NSMP South for Acorn use.
- A separate control centre for the subsea infrastructure

10.3 Other Utilities

10.3.1 Emergency Power

Emergency power and UPS will be provided either via tie-in to an existing St Fergus system or provision of a new standalone system.

10.3.2 Fire Water

For fire water the two options which will be considered are either tie-in to an existing system at St Fergus, or provision of a new Acorn specific system.

10.3.3 Potable Water

Potable water is required for emergency showers/eyebaths. This will likely be provided via a connection to the existing St Fergus water mains supply.

10.3.4 Service Water

Service water is required for process utility stations. This could be provided via either a connection to the existing St Fergus service water system or a connection to the mains water supply.

10.3.5 Nitrogen

Nitrogen is required for the purging of tanks and pressurisation if demanded by the technologies selected. There may be an opportunity to tie into existing nitrogen generation or storage facilities at the existing St Fergus plants. Only small quantities will likely be required.

10.3.6 Instrument Air

Compressed air is required for process control equipment such as actuators and for general use. The options are to size and purchase an air compressor package or tie into existing facilities at St Fergus. Instrument air is typically provided at 6barg.

10.3.7 Hydrogen for Process Plant

Supply of hydrogen may be required if, for example, catalytic oxidation is required for conditioning of the CO_2 product. Onsite hydrogen generation is uneconomic at the expected quantities, therefore the options are import and store onsite or tie-in to existing hydrogen lines.

10.3.8 Telecommunications

Phone lines will be required for operator use. This will be provided either from an extension from an existing St Fergus line or a dedicated line will be required.

10.3.9 Access & Security

Access roads are necessary both during operation and construction to the site also enabling access to process equipment for maintenance. Security fencing and gatehouses may also be necessary. There may scope to share facilities with neighbouring plants. Otherwise new infrastructure is required.

10.3.10 Welfare

Facilities such as a canteen, administration offices, changing areas and parking will be required for on-site staff. These will either be new, taking up an additional footprint, or sharing of facilities may be possible.

10.3.11 Process Drains and Waste Water Options

Two types of drains are anticipated to be included within the Acorn CCS project design - process area open drains and clean area open drains. Process area drains cover equipment bunding whilst clean area drains cover rainwater collection and surface runoff. The requirement for closed drains will also be considered.

The options which will be considered are:

- Tie-in to existing wastewater system at St Fergus
- Tie-in to a new Acorn CCS project wastewater system.

11.0 Subsea Infrastructure Options

11.1 Subsea Control Method Options

The options for the umbilical, subsea tree and subsurface safety valve (SSSV) are inter-related with respect to the actuation control method.

- Electric actuation of tree valves and SSSV
- Electric actuation of tree valves and self-actuating SSSV
- Hydraulic actuation of tree valves and SSSV

For example, if a hydraulic actuation method is chosen for the tree valves then hydraulic fluid needs to be supplied to the subsea equipment either via an umbilical or locally, whilst a fully electric system will be able to eliminate the requirement for hydraulic fluid.

A typical onshore equipment block diagram for a subsea development is shown in Figure 11-1.

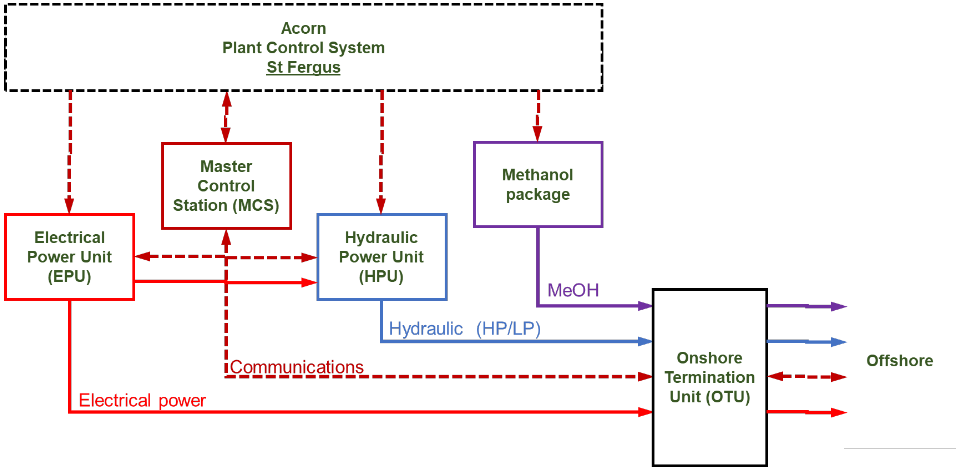

Figure 11-1: Onshore Equipment for a Conventional Umbilical

11.2 Tree Control Options

The subsea tree provides the integrity barrier and control for the well. An example subsea tree, complete with an over-trawlable protection structure is shown in Figure 11-2.

The options are:

- Electric actuation of tree valves and SSSV
- Electric actuation of tree valves and hydraulic actuation of SSSV
- Electric actuation of tree valves and self-actuating SSSV
- Hydraulic actuation of tree valves and SSSV
- Hydraulic actuation of tree valves and self-actuating SSSV

11.2.1 Electric/Hydraulic Option

Electro/hydraulic trees receive both electric power, communications and hydraulic fluid to a subsea control module (SCM), which uses the hydraulic fluid to open, and keep open, the tree valves and the SSSV.

11.2.2 Electric Option

Electrical trees receive only electric power and communications to open, and keep open, the tree valves and the SSSV.

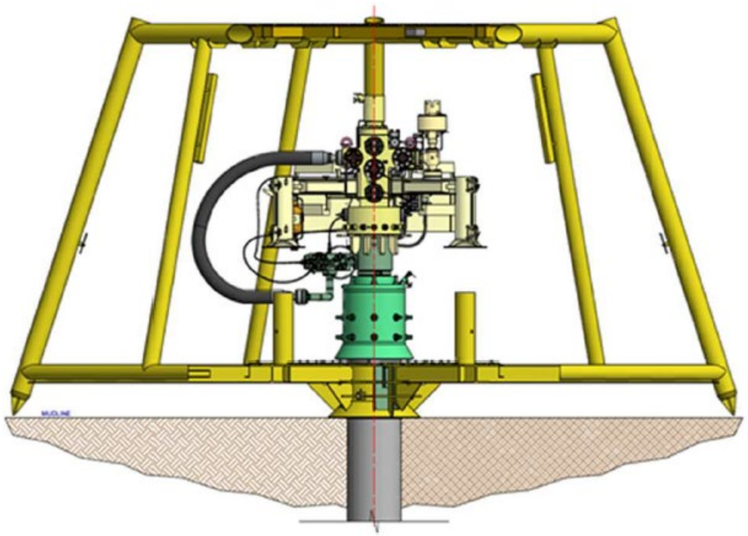

Figure 11-2: Subsea Tree with Typical Over-trawlable Structure (Image:OneSubsea)

11.3 Hydraulic Power Unit (HPU) Options

The hydraulic power unit (HPU) stores, pumps and filters the hydraulic fluid used to actuate the hydraulically actuated fail-safe tree valves and SSSV. The HPU supplies hydraulic fluid at low pressure (LP; typically 250-300barg) to the tree valves and high pressure (HP; typically 350-550barg) to the SSSV. The hydraulic fluid can be either oil based or water based. This is a decision that would be made in the Define phase.

An HPU will only be required if an electro/hydraulic tree and/or a hydraulic SSSV is chosen.

The options for the HPU are:

- A "dry" HPU where the hydraulic fluid is supplied to the tree via an umbilical from the shore-based location
- A "dry" HPU where the hydraulic fluid supplied to the tree via an umbilical from a nearby oil and gas platform
- A subsea HPU (sHPU) where the hydraulic fluid is stored subsea, local to the tree and a subsea hydraulic pump is used to raise the hydraulic fluid to pressure required by the tree
- No HPU (if all-electric solution selected)

11.4 Electrical Power Transmission Options

Power is required for the subsea control module, instrumentation and if required subsea hydraulic pumps.

Power transmission can be provided in one of three forms:

- Single-phase alternating current (1P-AC)
- Three-phase alternating current (3P-AC)

- Direct current (DC)

1P-AC systems have been the norm for subsea production systems for many years. The main benefit over other options is the ease by which power can be stepped down using transformers. However, 1P-AC suffers from considerable transmission losses due to the 'skin-effect'. As such, beyond ~70km it may pose reliability issues.

3P-AC can be used over longer step-outs than single-phase to a maximum of ~150km.

DC systems have no reactive transmission losses and are therefore advantageous over longer step-outs which will be encountered in the build-out phase.

11.5 Hydrate Inhibition Options

During operations the formation of solid hydrates of CO_2 and water can occur if certain conditions are met, i.e. presence of free water and pressure and temperature within the hydrate formation conditions. This can cause potential blockages or capacity reductions of the pipeline, other downstream equipment and within the well. To avoid hydrate formation in the pipeline and tree, a transport H_2O specification will be maintained.

During continuous operations, the CO_2 will displace the water away from the wellbore, meaning that continuous supply of inhibitor is unnecessary. However, in early field life the presence of water (or gas) in the well bore may be unavoidable when the well is shut in.

Inhibitor supply may also be required to equalise pressure across the SSSV or tree valves when starting-up after closing-in, after well intervention operations or after testing of the SSSV.

In the case of rapid depressurisation scenarios, expansion of supercritical CO_2 will cause considerable temperature reduction due to the Joule-Thomson effect, and may affect the choice of inhibitor.

The decision on the requirement and type of chemical inhibitors options commonly considered are:

- No chemical inhibitor
- Methanol (MeOH)
- Mono-ethylene-glycol (MEG)

11.5.1 Hydrate Inhibitor Supply Options

If hydrate inhibition is required, the hydrate inhibition can be supplied to the well via a number of different sources:

- Existing 4" pipeline from St Fergus
- Umbilical from St Fergus
- Umbilical from a nearby platform
- Subsea storage and pumping
- Intervention vessel
- Not required

In all cases, it is important that the assessment for the hydrate inhibition supply infrastructure includes the impact of meeting the demands of future build-out scenarios.

11.5.1.1 Inhibitor supplied via existing 4” pipeline option

The existing Goldeneye pipeline infrastructure includes a 4” service line running from St Fergus to the Goldeneye platform. It is piggybacked to the main 20” pipeline for 19.4km, after which it runs adjacent, 20m south for the remaining length. Originally carrying MEG, it is also expected to be re-useable for MeOH (if required). A full pipeline integrity and lifetime extension study will be required to confirm this.

11.5.1.2 Inhibitor supplied via the umbilical option

Provision of the hydrate inhibition injection lines in the umbilical (from shore or from a nearby platform) adds to the cost of the umbilical but could provide more certainty over the full life of the project compared to service line reuse and avoid an oversized inventory.

11.5.1.3 Inhibitor supplied via subsea storage and pumping

Storage of inhibitor chemicals could also be provided subsea, however if MeOH were used this might cause inherent environmental and safety considerations due to its toxicity.

11.5.2 Hydrate inhibition pumping and storage facilities

Various options exist for the hydrate inhibition storage and pumping facilities. The choices will depend on the supply option chosen, but include:

- Modify and reuse existing SEGAL MEG storage and pumping facilities located at the SEGAL site and tie-in to the umbilical or existing 4” pipeline
- Construct new storage and pumping facilities at new the Acorn CCS plant and tie-in to the umbilical or existing 4” pipeline
- Construct new storage and pumping facilities at a nearby platform and tie-in to the umbilical
- Not required

11.5.2.1 Reuse hydrate inhibition facilities

A 200m^3 storage tank is available at the SEGAL site with two 7kW injection pumps as well as drain sumps and pumps. The equipment is currently owned by SEGAL and was used for the providing MEG to the Goldeneye facilities. Limited modification is anticipated to achieve repurposing and the capacity of the equipment is expected to be sufficient.

11.6 Umbilical Options

A standard electro/hydraulic tree/SSSV would require an umbilical with the following elements:

- Fibreoptic (FO) cable for communications
- Electrical power transmission cables
- HP and LP hydraulic lines (if required)
- Chemical injection lines (if required)

Whilst a fully electric tree/SSSV would remove the requirement for the hydraulic lines.

Depending on the commercial availability of the nearby oil and gas infrastructure and the decision on the tree and SSSV, a number of possible umbilical configurations exist.

- A 102km electro/hydraulic umbilical from St Fergus (build-out would require a total umbilical length of over 150km)

- A 102km electrical umbilical from St Fergus (build-out would require a total umbilical length of over 150km)
- A shorter electro/hydraulic umbilical to a nearby platform
- A shorter electrical umbilical to a nearby platform
- Local power and communication (buoy)

11.6.1 Umbilical to shore options

An umbilical from shore is likely to be buried along the route of the Goldeneye pipeline for the majority of its length, although the first 20km may not be able to be fully trenched due to the rocky nature of the sea bed in this initial section and may require additional protection. The routing of the umbilical does pass through a Marine Protected Area (MPA) and the impact on the dunes would need to be considered. Consideration would also need to be given to the impact on the dune system.

11.6.2 Tie-in to nearby platform option

One option is to make use of an existing nearby oil and gas platform, providing suitable space and facilities exist to do so. Communications would be made via secure satellite to the Acorn control room for the subsea infrastructure. The location of platforms within 50km of the platform end are shown in Table 11-1.

Platform (Operator)	Distance from Goldeneye Pipeline End (km)	Platform Installation Date	Platform Cessation Date
Golden Eagle (CNOOC)	~32	2014	2029
Buzzard (CNOOC)	~41	2007	2037
Scott (CNOOC)	~46.9	1993	2025
Tartan A (Repsol Sinopec)	~48.9	1981	2022
Claymore (Repsol Sinopec)	~50	1977	2034

Table 11-1: Nearest Platforms to Acorn Storage Site (Cessation of Production (COP) Dates from (Wood Mackenzie, 2019))

11.6.3 Local power and communication

The final option is to provide power and communications via a local buoy (utilising wind power, wave power or another local power option). This option would restrict the tree option to either fully electric or require the use of a sHPU.

11.6.4 Umbilical build-out provision

In all cases it is important that the assessment for the umbilical infrastructure includes the impact of meeting the demands of future build-out scenarios. The build-out options for the umbilical include:

- Single well at Acorn South
- Two or more wells at Acorn South

- Two or more wells at Acorn South AND the Acorn Central wells

11.7 Subsea Infrastructure Options

11.7.1 Acorn South Field Layout Options

A new interface between end of Goldeneye pipeline and the infield CO_2 pipeline(s) to the wells(s) will be required.

A new pipeline will be required to connect the existing Goldeneye pipeline to the new injection well(s). As a minimum, this line will be sized according to the expected flowrates for the first injection well(s). In the case of build-out, an additional injection well(s) and infield pipeline(s) will be necessary. The subsurface work and the flow assurance work will inform these decisions.

The subsea infrastructure design will also need to allow for pre-commissioning/commissioning pigging and operational pigging (if required) and may also need to allow for a new 4” service line linking the existing 4” service line to the well. For the purposes of this document it is assumed that a manifold will need to be installed to provide pre-commissioning and commissioning pigging functionality.

The decisions here revolve around how pigging is provided for and what provision made for future build-out and how this will be accommodated.

The main options for consideration are:

- Pipeline end manifold (PLEM) designed for one well, with a pipeline, provisionally 1.2km long, from the PLEM to the well(s) location.
- PLEM designed for two wells, with a pipeline provisionally 1.2km long, from the PLEM to first well and provision for a second pipeline, as shown in Figure 11-3. The second infield pipeline will would be sized according to expected flowrates and has a provisional length of approximately 7.5km. NOTE: all well locations are preliminary and will be updated during the Concept Select phase.

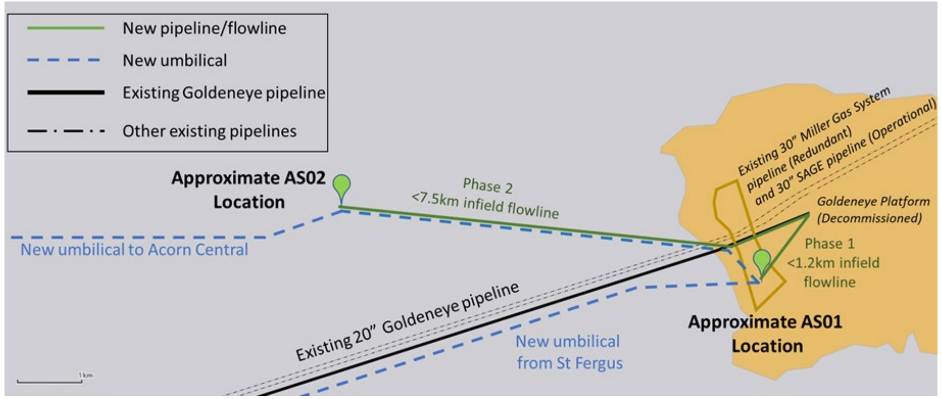

Figure 11-3: Acorn South Indicative In-field Pipeline Layout and Well Locations (Image: OGA)

- PLEM design based on daisy chaining the wells i.e. a connection to the first well designed for 4MtCO_2/yr capacity and provision the total Acorn South flow rate. Provision could be made at the first well for connection to the second well at the first well with a provisional capacity designed for 2MtCO_2/yr.
- No PLEM at the Goldeneye pipeline end and the first infield flow line sized to allow pigging through to the first well.

11.8 Pigging Options

11.8.1 Intelligent Pigging Options

An intelligent pigging campaign for the Goldeneye pipeline will confirm that the Goldeneye pipeline is fit for purpose.

The technologies that are available to assess wall thickness are magnetic flux leakage (MFL) and ultrasonic (UT). The latter provides more accurate detection although MFL produces acceptable results.

MFL pigging runs can be conducted in a wide range of fluids, including any mix of MEG/water and in gases. This enables like-for-like comparison to be conducted on reinspection whilst CO_2 product occupies the pipeline. Whereas any UT runs would need to be conducted in a slug of liquid.

Additional advantages of MFL are that the pipeline cleanliness is less crucial, the pig length is shorter and pigging speed is faster. Allowable bend radius would need to be considered during design stages.

11.8.2 Operational Pigging

Pigging of the Goldeneye and infield pipelines will be required for pre-commissioning (cleaning and drying) and potentially commissioning (filling) of the pipelines. The necessity of providing the tie-ins and equipment for this initial scope will ensure that it is available for operational pigging duties.

11.8.3 Onshore Pig Receiver Location Options

The existing pigging facilities for the Goldeneye pipeline are located on the east side of the SEGAL site, as shown in Figure 6-1. There are three main options for the pig launcher location:

- Re-use of existing pigging facilities on the SEGAL site for the intelligent pig only
- Re-use and reconditioning of the pigging facilities to allow use with CO_2 of existing pigging facilities on the SEGAL site
- New permanent pigging facilities on the Acorn plant
- Tie-ins for temporary pigging facilities on the Acorn plant

11.8.3.1 Minimum re-use of existing pigging facilities

In the first option the pigging facilities would be isolated after the IP and pre-commissioning. This supposes that operational pigging would not be required. The facilities may or may not be modified for commissioning.

11.8.3.2 Re-use of existing pigging facilities for operational pigging

In the second option operational pigging is assumed to be required. Acorn would modify the existing pigging facilities on the SEGAL plant for operational pigging duties.

11.8.3.3 New pigging facilities (permanent/temporary) for operational pigging

The third option is to provide new Goldeneye pigging facilities on the site of the compression and conditioning plant. This would either be via a temporary pigging connection or permanent launcher, to be confirmed based on the frequency of pigging operations.

12.0 Subsurface Options

12.1 Well Type Options

12.1.1 Injector Options

The primary well type for the Acorn CCS project is an injection well which is required to achieve injection of CO_2 into the Captain sandstone reservoir. The options to consider are:

- Vertical well (single branch or multi-lateral)
- Deviated well (single branch or multi-lateral)
- Horizontal well (single branch or multi-lateral)

Due to the high permeability of the Captain reservoir and the relatively low rate required during Phase 1 a single branch vertical or deviated well is likely to meet the project needs.

12.1.2 Water Producer Options

Water production wells may be required in CCS projects where pressure build-up following CO_2 injection benefits from the production of water from the aquifer. Due to the low storage volume required during this first phase of the Acorn CCS project a producer is not required and will not be carried forward as an option for Phase 1 of the project.

12.2 Well Construction & Control Options

12.2.1 Subsea Well Construction & Control Options

In order to meet the needs of Phase 1 of the Acorn CCS project, including meeting the low capex value driver, it is anticipated that a subsea well development will be most attractive. The control options to consider are as follows:

- Tie-back to St Fergus
- Tie-back to a nearby platform (e.g. Golden Eagle for first ~10 years)
- Combination (to a platform during Phase 1 for first ~10 years then tie-back to St Fergus after platform Cessation of Production (COP) and into Phase 2)

12.2.2 Topsides Well Construction & Control Options

In order to meet the needs of Phase 1 of the Acorn CCS project including meeting the low capex value driver it has been concluded that a dry-tree well option will be unattractive and as such will not be carried forward as an option for Phase 1 of the project.

12.3 Well Flowrate Envelope Options

12.3.1 Low Rate Design

In order to meet the needs of Phase 1 of the Acorn CCS project the options to consider for well flowrate envelope and associated injectivity are:

- 40- 345ktCO_2/yr
- 150 - 345ktCO_2/yr
- 190 - 345ktCO_2/yr
- 300 - 345ktCO_2/yr

The turndown required for the project is critical as it fundamentally impacts tubing sizing and potentially the number of wells needed.

12.3.2 High Rate Design

In order to meet the needs of Phase 2 of the Acorn CCS project a larger rate range should be considered which based on previous scoping work suggests the following as a reasonable range to consider:

- 1,000 ktCO_2/yr
- 1,500 ktCO_2/yr
- 2,000 ktCO_2/yr

The turndown required for the project is critical to define as it fundamentally impacts tubing sizing.

12.3.3 Well Availability Options (part of system)

Well availability is part of the overall system availability, however, it is mentioned here separately and should be part of an integrated assessment.

12.3.4 High Availability

With the planned injection of dry CO_2 in the dense phase well availability is expected to be exceptionally good. This option provides an overall well availability of 99%.

12.3.5 Medium Availability

With the planned injection of dry CO_2 in the dense phase well availability is expected to be very good. This option provides an overall well availability of 95%.

12.3.6 Low Availability

With the planned injection of dry CO_2 in the dense phase well availability is expected to be good. This option provides an overall well availability of 90%.

12.4 Number of Wells Options

12.4.1 One Well Option

In order to meet the Phase 1 “Low Rate Design” capacity requirements noted previously in Section 12.3.1 one well may suffice, which will also meet one of the primary value drivers of low capex, if not the two well option may be required.

12.4.2 Two Wells Option

In order to meet Phase 2 “High Rate Design” capacity requirements noted previously in Section 12.3.2, one well should suffice although no redundancy will exist especially if injectivity impairment is encountered. In this instance and as further “build-out” is needed then a two well design will be required.

12.5 Well Location Options

12.5.1 Areal Bottomhole Location Options

The Goldeneye field is planned to be the storage location for Phase 1 of the Acorn CCS project. To maximise storage volume, it is anticipated that a downdip location in the aquifer leg will be chosen, however, a range of possible options do exist as follows:

- Aquifer leg – west or south west of Goldeneye
- Aquifer leg – south of Goldeneye
- Aquifer leg – east or south east of Goldeneye
- Hydrocarbon leg – Goldeneye Field

12.5.2 Areal Seabed Location Options

The seabed location for Phase 1 well(s) consists of the following options:

- Optimised - With minor Phase 2 pre-investment (to make Phase 2 well(s) easier to drill & more cost-effective)
- Not optimised – With no Phase 2 pre-investment

12.5.3 Vertical Location Options (Primary Store)

The Captain sandstone consists of several members with the extensive upper Captain (D) sandstone being the key sand with ~65% of the storage volume, however, the less extensive lower Captain (A) sandstone should also be considered for injection purposes. As such the following options should be considered:

- Captain D Sand only
- Captain A Sand only
- Captain A + Captain D Sands combined

12.6 Completion Design Options

12.6.1 Upper Completion Options

A range of upper completion options exist with typical examples provided below:

- Single tubing string
- Dual tubing string
- Tubing sizing ($2^{7}/_{8}$”, 3½”, 4½“ etc..)
- Tubing material (carbon steel, 13% Cr, super 13% Cr, duplex)
- Seals material (aflas, ryton, other (yet to define)
- Self-Closing Subsea Safety Valve (SCSSSV) (hydraulic or electric)

12.6.2 Lower Completion Options

A range of lower completion options exist with typical examples provided below:

- No sand control – cased and perforated
- Yes sand control – slotted liner
- Yes sand control – screen only
- Yes sand control – open-hole gravel pack
- Yes sand control – cased-hole gravel pack

12.7 Subsurface Safety Valve (SSSV) Options

The SSSV is installed in the well and provides a fail-safe barrier in the event of loss of containment of the tree, for example damage by other sea users which would compromise the integrity of the tree.

The options for SSSV are:

- Hydraulic (surface controlled)
- Self-actuating
- Electric (surface controlled)

12.7.1 Hydraulic Option

The oil and gas industry standard for SSSVs is hydraulic actuation. In this case high pressure hydraulic fluid (typically >350barg) is used to actuate the SSSV.

12.7.2 Self-actuating Option

Non-return SSSV's, sometimes referred to as a storm chokes, are designed to close on loss of pressure in the well bore which might be expected if there is a loss of containment at the tree.

12.7.3 Electric Option

Another option that is available but may require qualification depending on the size chosen is an electric SSSV.

12.8 Well Monitoring Options

12.8.1 Tree Options

Monitoring of well performance is critical to ensure the well is operating within expected parameters. To achieve this well injection rates should be accurately measured, well injectivity should be monitored to allow early mitigation if an impairment is noted, downhole reservoir pressure and downhole temperature should be measured to ensure no over-pressuring of the reservoir and low temperatures should be monitored to avoid over-cooling and ensure that well integrity is preserved. Some of the measurement options are:

- No subsea meters
- Subsea choke used to measure rate
- Subsea meter used to measure rate
- Subsea pressure gauge(s)
- Subsea temperature gauge(s)

12.8.2 Well Downhole Options

In order to measure rate, pressure and / or temperature many options exist for in-well monitoring with a typical list provided below (although not all are fully proven in a subsea environment):

- Distributed temperature system (DTS - for low temp monitoring)
- Distributed acoustic system (DAS)
- Downhole pressure and temperature gauges (dual)
- Downhole rate meter

12.9 Annulus Monitoring & Blowdown Options

For the options below it is assumed that suitable annulus monitoring can be achieved and blowdown routes are available using appropriate actuation and control (e.g. to well or to sea). The options are:

- All-electric blowdown actuated facilities
- Electrohydraulic blowdown actuated facilities
- None

12.10 Subsea Filtration Options

The Goldeneye pipeline has a thin 40 – 80 micron epoxy coating in the inside of the Goldeneye 20" pipeline. In order to avoid the possibility of the Goldeneye pipeline liner becoming delaminated and blocking the well downhole it is suggested that subsea filtration equipment may need to be installed. Such equipment would likely need an online and standby to allow for easy re-routing (actuated or diver/Remotely Operated Vehicle (ROV)) during operation to avoid significant downtime.

If it is assessed that sand control is not required in injection wells it may also be concluded that no filtration is required since cased and perforated wells may benefit from thermally induced fracturing (from cold CO_2) negating the need for subsea filtration. Study work is required to perform the above assessment. The options to consider are summarised below:

- Subsea filtration – Actuated
- Subsea filtration – Diver/ROV intervention
- No subsea filtration
- Remove Goldeneye pipeline liner

13.0 Route to Market, Finance and Economics Options

13.1 CCS Business Model Options

Potential CCS business models, including those defined by the CCS Action Group (CAG) (CCS Action Group, 2019) and in the BEIS CCS Consultation (Department for Business, Energy and Industrial Strategy, 2019) will be considered for the Acorn CCS project. Through a planned engagement process with BEIS, the aim by the end of the Concept Select phase is to have, at minimum, clear line of sight to a CCS business model agreement, including commercial architecture and risk allocation. This activity continues in parallel with the BEIS consultation process for CCS business models.

13.2 Project Build-Out (Phase 2) Options

Acorn CCS project is the anchor CO_2 transport and storage solution for the Scottish industrial cluster and is a key element in the wider decarbonisation of the UK East Coast and North Sea countries.

Build-out options to expand the transport and storage business include CO_2 delivered from the proposed Acorn Hydrogen project, ship import and export of CO_2 via Peterhead, and the onshore transport of CO_2 via the Feeder 10 pipeline to the Acorn site at St Fergus from a customer base in Scotland. These are elements in the East Coast Deployment Plan (D22). These build-out projects would support a Phase 2 expansion of the Acorn CCS project in terms of subsurface storage, offshore transport and compression (with possible conditioning) onshore at St Fergus.

During the Concept Select phase early evaluation of the build-out options and preparation of a preliminary business case will be undertaken to understand where low regret investment could be made in Phase and to support entry into the Concept Define phase.

13.3 Project Agreements Options

Agreements will be required to secure CO_2 capture and compression and conditioning plant sites, flue gas/CO_2 supply, utilities, operations support, access and power supply at St Fergus. Options exist for some of these elements and the optimum configuration will be defined working in parallel with the technical work scope, based on requests for services and indicative rates. The maturity of commercial agreements required at the end of the Concept Select phase will be dependent on the existing optionality for that particular site or service, single points of failure requiring firmer agreements. A commercial framework will also be required to support access to the Goldeneye pipeline(s).

13.4 Supply Chain Options

Contracting strategy (through Define phase), Concept Select phase contracts and preparation for Define phase contracts (FEED) will be worked in parallel to the technical work scope.

13.5 Commercial Risk Management Options

Commercial risks will be identified, assessed and managed using a common process across the project. Specific risk issues, such as risk allocation within the CCS business model, will also be addressed independently.

13.6 Economics Options

Economic models will be developed in parallel to business model evaluation, defining assumptions, building economic models and evaluating options. A common economic model will be developed for evaluation between PBDE and its industry partners.

13.7 Financing Options

Preliminary financing plans will be developed during the Concept Select phase, working in parallel with business model evaluation and development.

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Appendix 1 – Options Summary Tables

Emission Source	Site size	Site Selection	Site Split	Availability	Equipment Sparing	Minimum Turndown	Capture Plant Design Life	Compression/ Conditioning Plant Design Life	Utlilities & Services Design Life	Offshore Design Life	Align Composition with Northern Lights	H_2O Specification
SEGAL - single gas turbine 150kt	Acorn CCS only	SEGAL - slug catcher	No Split	<90%	1 x 100%	40kt/yr	10 years	10 years	10 years	10 years	Yes	30ppmv (NL)
SEGAL - both gas turbines 300kt	Acorn CCS and compression/ conditioning of Acorn H2 CO2	NSMP South	Between LP & HP	90%	2 x 50%	150-180kt/yr	15 years	15 years	15 years	15 years	No	50ppmv
SEGAL - both gas turbines AND NSMP furnaces 345kt	Inclusion of provision for Feeder 10 compression	Blackhill	Between stripper & LP	95%	3 x 50%	190kt/yr	20 years	20 years	20 years	20 years		>50ppmv
NSMP hot oil furnaces 30kt		SEGAL - Unit 2600	Between absorber & stripper		2 x 100%	300-330kt/yr	20+ years	20+ years	20+ years	20+ years		
NSMP - hot oil AND glycol furnaces 40kt		NSMP North			2 x 70%							
CO2 removal from production gas		SEGAL - construction area										
National grid emissions												

O_2 Specification	SOx Specifcation	NOx Specification	Capture Technology	Capture Plant Supplier	Capture Plant Recovery Specification	Flue Gas Preconditioning - Requirement for SOx/NOx Removal	Cooling Technology	Heating for Stripper Column	Heating Medium	DCC Waste Water Treatment	Solvent Reclaimer Waste Management	Liquid Solvent Absorber Vent Gas
5ppmv	100ppmv	100ppmv	Amine	To be defined (technical/ commercial)	Low: 85%	Required to meet vendor requirements	WHRU	WHRU	Steam	Tie-in directyl to existing wastewater systems	Treatment onsite before transporting offsite	Vent directly to atmosphere
10ppmv (NL)	10ppmv (NL)	10ppmv (NL)	Hot potassium carbonate		Base case: 90%	Required to meet compositional specification	Seawater cooling	WHRU plus gas heater	Hot oil	Tie-in to new Acorn wastewater system	Transport offsite without onsite treatment	Scrubbing
			Chilled Ammonia Process		High: 95%	Not required	Air cooling (fin-fan)	WHRU plus electric heater	Direct immersion heater	Requirement for chemical neutralisation		
			Carboxylic acid				Cooling tower - open	Gas heater		Collect and transport offsite for treatment		
			Physical solvent				Cooling tower - closed	Electric heater				
							Chiller package (export cooling only)					
							DCC					

Process Drains	Demin Make-up Water	LP Compression Technology	LP Turndown	HP Turndown	O_2 Removal Technology	Moisture Removal Technology	Conditioning (MP) Pressure	HP Compression Technology	Export Pipeline Inlet Pressure	Chiller Package	Metering Locations & Accuracy (depending on operators)	Metering Technology - Flue Gas & CO2 Gas Phase
Tie-in to new wasrtewater system	New generation system	Integrally geared compressor	Variable inlet guide vanes	Variable inlet guide vanes	Catalytic oxidation	Solid dessicant (molecular sieve)	20 barg	Integrally geared compressor	90bar	Propane	Upstream boundary at SEGAL/NSMP sites	Ultrasonic
Tie-in to existing	Supplied via tote tanks	Reciprocating compressor	Suction throttling	Suction throttling	Chemical scavenging	Liquid dessicant (TEG absorption)	25 barg	Multi-stage centrifugal compressor (2 stage)	100bar	CO2 slipstream	Capture plant vent	Thermal probe for LP
	Tie-in to existing	Multi-stage centrifugal compressor	Variable speed	Variable speed	Physical removal from dry CO2	Low temperature separation	30 barg	Ramgen supersonic	110bar	R-134A	Between capture and compression plants	
		Screw compressor	Recycle	Recycle	Physical removal from rich solvent	Supersonic separation				Ammonia	Compression/ conditioning plant vent	
		Ramgen supersonic compressor				Membranes				Isobutane	Dense phase post compression/ conditioning plant	
											Dense phase at well	

Metering Technology - CO2 Dense phase	Compositional Monitoring	Power	Control Room Location	Emergency Power	Fire Water	Potable Water	Service water	Nitrogen	Instrument Air	H2 for Process Plant	Telecom.s	Access & Security (emergency, operations, maintenance)
Corilois	Continuous	New connection to the national power grid	New standalone control room at Acorn site	Tie-in to existing system	New firewater pumps	New	New	New	New	New	New	New
Ultrasonic	Discrete samples	New gas fired power onsite with CCS	Combined with NSMP	New system	Tie-into existing system at St Fergus	Tie into existing system	Tie into existing system	Tie-in to existing	Tie-in to existing	Tie-in to existing	Tie-in to existing	Use existing
Orifice plate		Organic Rankine cycle	Combined with SEGAL									
		Local renewable power	Repurposing former Miller control room at NSMP South									
			Separate new control centre for subsea infrastructure									

Welfare	Subsea Control Method - Tree Valves	X-Tree Control	HPU	Electrical Power Transmission	Well Hydrate Inhibitor	Hydrate Inhibitor Pumping & Storage Faciltites	Umbilical Configuration	Umbilical Build-Out Provision	Acorn South Field Layout	Intelligent Pigging Technology	Onshore Pig Reciever Location	Well Type (Trajectory)
New	Electric	Fully electric	Dry - hydraulic fluid supplied from shore	Single phase alternating current (1P-AC)	No chemical inhibitor	Onshore - modify & reuse SEGAL MEG faciltites	102km electro/hydraulic umbilical from St Fergus	1 well at Acorn South	PLEM for 1 well with ~1.2km infield pipeline	Magnetic flux leakage	Re-use existing facilities at SEGAL for IP only	Vertical (single branch or multi-lateral)
Use existing facilities	Hydraulic	Electric with hydraulic SSSV	Dry - hydraulic fluid supplied from nearby platform	Three phase alternating current (3P-AC)	MeOH	Onshore - new facilties	102km electric umbilical from St Fergus	2 or more wells at Acorn South	PLEM for 2 wells with 1 infield pipeline & provision for 2nd infield pipeline	Ultrasonic	Re-use existing facilities at SEGAL and repurpose for operational pigging	Deviated well (single branch or multi-lateral)
		Electro/Hydraulic	Subsea	Direct Current (DC)	MEG	New facilties on platform	Shorter electro/hydraulic umbilical from nearby platform	2 or more wells at Acorn South and Acorn Central	PLEM design based on daisy-chain from 1st to 2nd well		New permanent facilities at Acorn plant	Horizontal (single branch or multi-lateral)
			None			Not required	Shorter electric umbilical from nearby platform		No PLEM at GE pipeline end - size infield pipeline to allow pigging to well		Tie-ins for temporary pigging facilities at Acorn plant	
							Local power & communication (buoy)					

Well Flowrate Envelope - Low Rate	Well Flowrate Envelope - High Rate	Well Availability	Number Of Wells	Well Location - Areal Bottomhole	Well Location - Areal Seabed	Well Location - Vertical Location	Completion Design - Upper	Well Material Selection - Metallurgy	Well Material Selection - Seals	Completion Design - Lower	SSSV	Well Monitoring - Subsea
40-345+kt/y	1000kt/y	High - 99%	1	Aquifer leg - West of SW of Goldeneye	Optimised - minor preinvestment for Phase 2	Captain D Sand only	Single $2^{7}/_{8}$" tubing string	Carbon steel	AFLAS	Cased & perforated	Self-actuating SSSV	None
150-345+kt/y	1500kt/y	Medium - 95%	2	Aquifer leg - South of Goldeneye	Not optimised - no preinvestment for Phase 2	Captain A Sand only	Dual $2^{7}/_{8}$" & 4½ " tubing string	13Cr	Ryton	Sand control - slotted liner	Electric SCSSSV	Subsea choke used to measure rate
190-345+kt/y	2000kt/y	Low - 90%		Aquifer leg - East or SE of Goldeneye		Captain A & D Sands combined	Other single tubing	Super 13Cr	Other (yet to define)	Sand control - screen only	Hydraulic SCSSSV	Subsea meter used to measure rate
300-345+kt/y				Hydrocarbon leg - Goldeneye Field			Downhole choke	Duplex		Sand control - open-hole gravel pack	Electric SSSV	Subsea pressure gauge(s)
										Sand control - cased-hole gravel pack	Hydraulic SSSV	Subsea temperature gauge(s)

Well Monitoring - Well	Well Annulus Monitoring & Blowdown (Subsea)	Subsea Filtration
DTS - low temperature monitoring	All electric blowdown actuated facilities	Subsea filtration - actuated
Distributed acoustic system (DAS)	Electrohydraulic blowdown actuated facilites	Subsea filtration - driver/ROV intervrention
Downhole pressure and temperature meter	No option	No subsea filtration
Downhole rate meter		Remove Liner