Project: ACT Acorn Feasibility Study

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The ACT Acorn consortium is led by Pale Blue Dot Energy and includes Bellona Foundation, Heriot-Watt University, Radboud University, Scottish Carbon Capture and Storage (SCCS), University of Aberdeen, University of Edinburgh and University of Liverpool.
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1.0 Executive Summary

Acorn CCS is a strategically phased, industrial carbon capture and storage project with European PCI status.

It takes best advantage of the UK’s built and natural assets, to deliver low-cost, low-risk, commercial scale CCUS infrastructure to catalyse clean growth opportunities in the North East of the UK and beyond.

The underlying commercial assumption is that the CO₂ transport and storage service is provided as a utility service with a capped return of 8%.

The £14/T unit cost of storage in Phase 2 is 90% less than in Phase 1 and clearly illustrates the economies of scale possible from better asset utilisation.

The operational flexibility of the development plan ensures that the costs incurred during Phase 2 are strongly linked to the demand for services.

In the event that CCUS does not form part of the UK decarbonisation pathway, the regret costs of Phase 1 are limited to £370 million.

Acorn CCS was adopted as a European Project of Common Interest (PCI) in the third Union List in November 2017. The Acorn PCI aims to establish, through a phased buildout programme, a strategic, transnational CO₂ transport infrastructure capable of delivering over 12MT/yr of CO₂ from emitters around the North Sea Basin, to mature, secure, geological storage sites deep below the North Sea.

The main objectives of this D15 report are to document the decision focussed economic spreadsheet model developed to evaluate the Acorn development and to record the results insights from preliminary economic analysis.

Phase 1 enables the rapid commissioning of large scale (5-6MT/yr) offshore CO₂ transport and storage infrastructure, using commercial scale quantities of ‘easy to capture’ CO₂ from key emission points at the St Fergus Gas Terminal in north east Scotland.

Phase 1 requires a capital investment of £276 million and an estimated operating expenditure of £341 million over the 20 year evaluation horizon. This requires a revenue of approximately £184/T to achieve a zero NPV using an 8% discount rate.

A £629 million operating payment from Government has been assumed in Phase 1, along with a service fee of £30/T charged to the CO₂ emitter.

In Phase 2, a transport and storage fee of £19/T enables the build out of Acorn CCS to achieve a zero NPV and the government to recover its investment in Phase 1 via a clawback mechanism.
The transport and storage fee required for Phase 2 to achieve the economic hurdle is heavily influenced by the assumed level of government cost recovery. This ranges from £19/T for 100% recovery to £12/T if there is no cost recovery.

The capital and operating costs for Phase 2 are highly dependent upon the level of CO₂ supply and demand for transport and storage services. A sensitivity assumed that demand was reduced by 73% and this resulted in in a 69% reduction in the costs.

This D15 document draws on many of the deliverables already completed and issued during the ACT Acorn project, as well as the D16 – Acorn Full Chain Development Plan and Budget report which is being issued concurrently with this report.

The timing of additional quantities of CO₂ for the build out phase of Acorn CCS, will depend on the decarbonisation route taken by the UK. However, the work completed as part of the D02 – CO₂ Supply Options report, indicates that additional CO₂ should arrive at St Fergus by 2024. Likely expansion opportunities include: processing of additional quantities of CO₂ arriving at St Fergus from repurposing of the redundant onshore gas pipeline (Feeder 10) between St Fergus and Central Scotland, and CO₂ imports via the nearby, deep water port at Peterhead. Around 35% of all UK natural gas currently comes onshore at the St Fergus terminal, with CCUS facilities available, St Fergus would be perfectly positioned to become a major low-carbon hydrogen production hub. Details are provided in the D18 – Expansion Options report.
2.0 Introduction to ACT Acorn

2.1 ACT Acorn Overview

ACT Acorn, project 271500, has received funding from BEIS (UK), RCN (NO) and RVO (NL), and is co-funded by the European Commission under the ERA-Net instrument of the Horizon 2020 programme. ACT grant number 691712. ACT Acorn is a collaborative project between seven organisations across Europe being led by Pale Blue Dot Energy in the UK, as shown in Figure 2-1.

Figure 2-1: ACT Acorn consortium partners

The research and innovation study address all thematic areas of the ACT Call including ‘Chain Integration’. The project includes a mix of both technical and non-technical innovation activities as well as leading edge scientific research. Together these will enable the development of the technical specification for an ultra-low cost, integrated CCS hub that can be scaled up at marginal cost. It will move the Acorn development opportunity from proof-of-concept (TRL3) to the pre-FEED stage (TRL5/6) including iterative engagement with relevant investors in the private and public sectors.

Specific objectives of the project are to:

1. Produce a costed technical development plan for a full chain CCS hub that will capture CO₂ emissions from the St Fergus Gas Terminal in north east Scotland and store the CO₂ at an offshore storage site (to be selected) under the North Sea
2. Identify technical options to increase the storage efficiency of the selected storage site based on scientific evidence from geomechanical experiments and dynamic CO₂ flow modelling and through this drive scientific advancement and innovation in these areas.
3. Explore build-out options including interconnections to the nearby Peterhead Port, other large sources of CO₂ emissions in the UK region and CO₂ utilisation plants
4. Identify other potential locations for CCS hubs around the North Sea regions and develop policy recommendations to protect relevant
infrastructure from premature decommissioning and for the future ownership of potential CO$_2$ stores.

5. Engage with CCS and low carbon economy stakeholders in Europe and worldwide to disseminate the lessons from the project and encourage replication.

CCS is an emerging industry. Maturity improvements are required in the application of technology, the commercial structure of projects, the scope of each development and the policy framework.

The key areas of innovation in which the project will seek insights are summarised in Figure 2-2.

### Subsurface science
- Understanding storage efficiency
- Geomechanics and rock strength
- Site selection & evaluation

### Economic efficiency
- Minimum viable development
- Growth and build out
- Business models

### Policy recommendations
- Just transition to regional decarbonisation
- Decommissioning hydrocarbon infrastructure
- Infrastructure re-use for CO$_2$ activity

### Societal impact
- Perceptions and acceptance
- Replication around the World
- Life-cycle analysis

Figure 2-2: Key areas of innovation

The project activity has been organised into 6 work packages as illustrated in Figure 2-3. Specific areas being addressed include; regional CO$_2$ emissions; St Fergus capture plant concept; CO$_2$ storage site assessments and development plans; reservoir CO$_2$ flow modelling, geomechanics; CCS policy development; infrastructure re-use; lifecycle analysis; environmental impact; economic modelling; FEED and development plans; and build out growth assessment.

The project will be delivered over a 19-month period, concluding on the 28th February 2019. During that time, it will create and publish 21 items known as Deliverables. Collectively these will provide a platform for industry, local partnerships and government to move the project forward in subsequent phases. It will be driven by business case logic and inform the development of UK and European policy around infrastructure preservation. The deliverables are listed in Table 2-1.

Figure 2-3: ACT Acorn work breakdown structure
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<td>D02 CO₂ Supply Options</td>
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<td></td>
<td>D17 Feeder 10 Business Case</td>
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<td>2) Site Screening &amp; Selection</td>
<td>D03 Basis of Design for St Fergus Facilities</td>
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<td>D04 Site Screening Methodology</td>
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<td>D05 Site Selection Report</td>
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<td>D13 Plan and Budget for FEED</td>
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<td>3) Expansion Options</td>
<td>D18 Expansion Options</td>
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<tr>
<td>4) Full Chain Business Case</td>
<td>D10 Policy Options Report</td>
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<td>D11 Infrastructure Reuse Report</td>
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<td>D14 Outline Environmental Impact Assessment</td>
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<td>D16 Full Chain Development Plan and Budget</td>
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<td>5) Geomechanics</td>
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<td>D19 Material for Knowledge Dissemination Events</td>
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<td>D20 Publishable Final Summary Report</td>
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*Table 2-1: ACT Acorn Milestones and Deliverables*
The Consortium includes a mix of industrial, scientific and CCS policy experts in keeping with the multidisciplinary nature of the project. The project is led by Pale Blue Dot Energy along with University of Aberdeen, University of Edinburgh, University of Liverpool, Heriot Watt University, Scottish Carbon Capture & Storage (SCCS), Radboud University and The Bellona Foundation. Pale Blue Dot Energy affiliate CO2DeepStore are providing certain input material.

2.2 Acorn Development Concept

Many CCS projects have been burdened with achieving “economies of scale” immediately to be deemed cost effective. This inevitably increases the initial cost hurdle to achieve a lower lifecycle unit cost (be that £/MWh or £/T) which raises the bar from the perspectives of initial capital requirement and overall project risk.

The Acorn development concept use a Minimum Viable Development (MVD) approach. This takes the view of designing a full chain CCS development of industrial scale (which minimises or eliminates the scale up risk) but at the lowest capital cost possible, accepting that the unit cost for the initial project may be high for the first small tranche of sequestered emissions.

Acorn will use the unique combination of legacy circumstances in North East Scotland to engineer a minimum viable full chain carbon capture, transport and offshore storage project to initiate CCS in the UK. The project is illustrated in Figure 2-4 and seeks to re-purpose an existing gas sweetening plant (or build a new capture facility if required) with existing offshore pipeline infrastructure connected to a well understood offshore basin, rich in storage opportunities. All the components are in place to create an industrial CCS development in North East Scotland, leading to offshore CO2 storage by the early 2020s.
A successful project will provide the platform and improve confidence for further low-cost growth and incremental development. This will accelerate CCS deployment on a commercial basis and will provide a cost effective practical stepping stone from which to grow a regional cluster and an international CO₂ hub.

The seed infrastructure can be developed by adding additional CO₂ capture points such as from hydrogen manufacture for transport and heat, future CO₂ shipping through Peterhead Port to and from Europe and connection to UK national onshore transport infrastructure such as the Feeder 10 pipeline which can bring additional CO₂ from emissions sites in the industrial central belt of Scotland including the proposed Caledonia Clean Energy Project, CCEP. A build out scenario for Acorn used in the 2017 Projects of Common Interest (PCI) application is included as Figure 2-5.

Pale Blue Dot Energy is exploring various ways and partners to develop the Acorn project.
3.0 Scope

3.1 Purpose

The purpose of ACT Acorn Deliverable 15 Economic Model and Documentation (D15) is to document the economic and strategic assumptions in the storage development plans for the Acorn storage site and assess their impact.

3.2 Scope

The Deliverable Scope covers the following aspects:

- Decision-focussed economic model built in Excel
- Model to be capable of being run in probabilistic or deterministic mode
- Model to be capable of running multiple scenarios
- Calculation of a range of value metrics
- Documentation including user guide
- Data input book
- Results and Analysis

3.3 Assumptions

Cost assumptions for Acorn Phase 1 are documented in D16 – Acorn Full Chain Development Plan and Budget.

The overall commercial model adopted is one of a utility-type service with a capped rate of return. The modelling assumes an 8% cost of capital and nominal discount rate.

Additional details are provided in Annex B.
4.0 Rationale

This chapter describes the key elements of logic and rationale used to develop the spreadsheet model, as well as providing relevant context.

4.1 Overview

The economic model of the Acorn project is built to evaluate the business case, from the perspective of the store operator. The model can accommodate a wide range of scenarios and this report focuses the evaluation of one, reference scenario which includes the added value of building the project out to fully utilise the transport and storage infrastructure available. To achieve this aim, the investment and operational activity is separated into phases:

- **Phase 1**: The base case development for the ACT Acorn project. CO₂ is captured (starting at 200kT/yr) at the St Fergus Gas Terminal and transported using the existing Atlantic pipeline to be injected in the Acorn storage site in the Captain aquifer.

- **Phase 2**: Further build out of the Acorn project according to CO₂ profiles developed within ACT Acorn D02 CO₂ Supply Options (D02). From D02, both the developed scenarios, A and B can be run in the model, however Scenario A has been used for the D15 analysis. Transport of CO₂ is through the Atlantic pipeline until such a time that the capacity limit is reached, at this point the Goldeneye pipeline would be commissioned and injection into the Goldeneye area of the Acorn store commences.

Utilising separate phases of activity allows the project to evaluate the benefits of each phase separately and in combination, whilst remaining flexible to using different investment and revenue models in each phase.

4.2 Strategic Context

4.2.1 Phase 1

The first phase of the project includes the construction of capture plant, compression, recommissioning of the Atlantic pipeline and the introduction of subsea injection infrastructure to enable CO₂ to be injected into the Acorn CO₂ storage site. CO₂ would be captured from existing sources at St Fergus, i.e. gas fired turbines and heaters used in natural gas processing. The first phase of the project is intended to create the beginning of a transport and storage infrastructure that is scalable to achieve a significant contribution towards the UK’s carbon emission reduction targets. As an enabler project the first phase includes small scale capture of existing emissions at St Fergus, however, with the exception of compression and well requirements, the transport and storage infrastructure is full scale from day one. The first phase of the project will begin injecting 200kT/yr of CO₂ into the Captain aquifer.

A minimum viable transport and storage project based at St Fergus can enable the UK government to begin delivering the roadmap set out in the Clean Growth Strategy. Growing transport and storage infrastructure enables decarbonisation in more challenging areas, great strides have been made in low carbon power however some industrial processes inherently produce CO₂ irrespective of heat and power sources. CCS will play a role in decarbonising heat through the use
of hydrogen as an energy vector particularly through a transition period where a cost effective large-scale solution involves the reformation of fossil fuels.

Over the assumed 20 year operational life of Phase 1, 4.2MT of CO₂ are stored.

4.2.2 Phase 2

Implicit in the second phase is the adoption of CCS as a key approach to achieving UK commitments to reduce carbon emissions as set out in the Clean Growth Plan, Carbon Budget and the Paris Agreement.

The CO₂ supply assumptions are technology agnostic and could come from a variety of emission sources including: power generation, bioenergy or general industry. This assumes that carbon sequestration is appropriately incentivised and CO₂ transport links to St Fergus are constructed including the conversion of the Feeder 10 pipeline and the construction of CO₂ receiving facilities at Peterhead Port with a transfer line to St Fergus.

This second phase of operations covers the build out of the Acorn project utilising the scenarios developed in the D02 report which identified 30 potential significant sources of CO₂. The analysis in this report principally uses Scenario A from D02 which included 12 sources of CO₂ supply as illustrated in Figure 4-1. The model includes several checks or constraints to ensure that only sources that can be fully serviced are accepted and that the combined rates do not exceed those of the infrastructure. These are discussed more fully in the following section.

Over the assumed 38-year operational life of Phase 2, 143MT of CO₂ are stored.

**Figure 4-1: Potential CO₂ supply for Phase 2**

4.3 Store Capacity and Infrastructure Constraints

The model includes three forms of constraint that combine to ensure that only CO₂ supplies that can be fully serviced are accepted and that additional elements of infrastructure are added in time to service planned system users. The three factors are:

- Capacity of the CO₂ store
- Throughput capacity of the offshore pipelines
- Operational infrastructure (additional injection wells and compression modules)
4.3.1 Store Capacity Constraint

The inventory of 30 potential sources of CO\(_2\) identified in D02 are shown in Figure 4-2. The 12 sources that form Scenario A in D02 are shown by orange bars. Seven of those can be accommodated in the Acorn CO\(_2\) store, and are accepted into the Acorn CCS system, these also have a green bar on the chart.

The model logic has been designed to mimic the perspective of the store operator who will only accept additional sources of CO\(_2\) if there is sufficient remaining capacity within the store to accommodate the forecast lifetime CO\(_2\) from that source. The logic behind source selection simply looks at whether the lifetime emissions of the source can be stored without reaching the capacity limit. If the emissions can be stored the source is accepted. This simplified view does not consider the development of further stores or any information about the source itself and purely looks at the amount of CO\(_2\) that needs to be stored.

It is recognised that this is a simplifying assumption and that in practise the store operator may seek to expand the capacity of the store in order to service new customers. The order of the list in Figure 4-2 is somewhat arbitrary. The assumed store capacity is 150MT of CO\(_2\) and Figure 4-2 illustrates how the remaining capacity of the stored reduces as additional customers join the system. Figure 4-2 illustrates how the 250MT of potential CO\(_2\) source in D02 Scenario A has been curtailed so that the total inventory of sources accepted into the Acorn CCS system is less than the appraised store capacity of 150MT.

4.3.2 Pipeline Throughput Capacity Constraint

The project starts with the reuse of the Atlantic pipeline which has an assumed throughput capacity of 5MT/yr of CO\(_2\). If the combined throughput rate of the users accepted onto the system is forecast to exceed this amount, then the Goldeneye pipeline is brought into service and wells drilled in that part of the Acorn store.

The combined throughput capacity requirement never exceeds the 9MT/yr aggregate capacity of the two pipelines, using current assumptions. The model has the functionality to investigate the impact of curtailling throughput if the pipelines were constrained for some reason.

The model does not consider the capital and operating expenditure required to capture and transport the CO\(_2\) to St Fergus, which could be via Feeder 10 or shipping to Peterhead, however it does include incremental investment in the compression and injection capacity. The CO\(_2\) profiles use the sources identified in the D02 ACT Acorn CO\(_2\) Supply Options report (Pale Blue Dot Energy, 2017). Whilst Scenario A in the CO\(_2\) Supply Options report has a peak supply rate of 9MT/yr, within the model transported CO\(_2\) volumes have been capped to circa 5MT/yr to match the capacity constraint of the Acorn CO\(_2\) storage site and happens to be less than the capacity constraint of the Atlantic pipeline. Figure 4-2 illustrates how sources were analysed and selected for inclusion in the Phase 2 profile. The modelling logic looked at each emission source in turn and compared the total emissions with the remaining capacity in the store, if there was not enough capacity remaining for the lifetime of the emission source then it was not included in the profile. The model makes no attempt to gauge how likely a project is to proceed and makes no judgement based on the type of technology being considered. In reality there would be far more factors that play into the decision on whether to accept CO\(_2\) emissions or not. Additionally, as the store edges closer to the capacity limit the storage operator is likely to begin developing a new storage site to provide continuing service for existing and new captured emission sources.
Figure 4-2: Emission sources included in Phase 2
4.4 Operational Infrastructure

The development of Phase 1 is well defined in terms of the CO₂ supply sources, the injectivity required, number of wells, compression etc.

For Phase 2 the model determines the infrastructure requirements based on the future CO₂ supply profile.

The bars on Figure 4-3 show the annual CO₂ injection profile, which determines the requirements for compression, pipeline capacity and injectivity.

The model takes this CO₂ supply profile and determines how many modules of compression are required based on the assumption that each compression module can process approximately 525kT CO₂ from 1bar to 120bar. Compressors are installed two years before they are needed. A check is made to ensure that the pipelines can transport the compressed CO₂; the Atlantic pipeline is used first and if its’ capacity limit is reached then the Goldeneye pipeline is commissioned.

The model then calculates the well requirements based on an assumption that each well has an injectivity capacity of 1.5MT/yr and a lifespan of 20 years. Wells are also assumed to be drilled two years before they are required for injection. Figure 4-4 illustrates the number of wells drilled in each year and the total number of wells that are operational in each of the two drill centres. In the scenario modelled, wells are only required in the Atlantic area. A total of 6 wells are drilled but due to the longevity constraint a maximum of 3 wells are operational at any point in time.

Figure 4-5 details the infrastructure requirements required to service the CO₂ injection profile in Phase 2. Wells and compression units are assumed to be constructed two years before they are needed. The compression units, once installed, are assumed to be turned up or down depending on the current CO₂ throughput required.
4.5 Revenue Model

The model has been designed to be capable of applying different revenue models in each of the phases. This is intended to reflect the situation where an initial catalyst development is substantially publicly funded whereas the subsequent phase is a solely commercial venture.

4.5.1 Phase 1

Phase 1 is the catalyst development, where the priority is to begin capturing and storing CO₂ whilst at the same time enabling infrastructure for a subsequent build out phase. Only a modest amount of CO₂ is captured in this catalyst phase and without some form of government support is considered unlikely to proceed.

The revenue model for Phase 1 has the following three components that can be combined in different ways to evaluate a large number of model options.

1. Grant from the public sector;
2. Operating payment from the public sector; and
3. Service fee from the CO₂ emitter.

In the scenario discussed in this report the grant component is set to zero and the underlying assumption is that the capital will be financed through the private sector underwritten by public sector funding via the operating payment.

The level of operating payment and service fee have been calculated to deliver a zero net present value (NPV) at a real discount rate of 5.4% (8% in nominal terms). The two quantities are applied in the same manner, on a per ton basis, and are inversely related so that the zero NPV condition is honoured.
A service fee (to cover CO₂ transport and storage) of £30/T was selected. Whilst this selection is somewhat arbitrary, it is felt by the authors to represent a reasonable level for the service.

An operating payment of £154/T CO₂ stored is required.

4.5.2 Phase 2

Phase 2 is a wholly commercial venture and revenue relies solely on the service fee. However, to try and reflect a situation where the transport and storage venture has a cap on the economic returns that it is allowed to make (for example in a regulated asset model style arrangement) the service fee has been calculated to generate a zero NPV in this phase.

In the Phase 2 build out, CO₂ is assumed to be delivered to the St Fergus terminal. Emitters who export their CO₂ to be stored using the existing infrastructure will be charged a transport and storage fee. This fee is used to fund future investment in throughput and storage capacity as well as to cover the operating costs of the development.

The transport and storage fee in Phase 2 is £20/T.
5.0 Business Case

5.1 Critical Success Factors

The following attributes are essential to the successful delivery of the scheme and are the critical success factors.

**Strategic fit**
How well the project meets the objectives and related requirements of the UK government and investors. Potential synergy with other programmes and project activity.

**Value for money**
The likely return on investment in terms of benefits to economy and wider society.

**Deliverability**
Degree to which the option could be delivered by the proposed organisation and matches the available skills required. The degree of technical maturity and applicability that can be delivered within the timescale.

**Affordability**
How likely the project is to be funded and how strong the business case would be for each option.

5.2 Cost Estimate Basis

Cost estimates are prepared throughout the various phases of a large project development process. Estimate types are based on a standard international approach, (AACE International, 2016), and vary from Type 5 (least accurate) to Type 1 (most accurate) as the definition of each opportunity develops and matures through the process. Thus, progressing from a factored methodology to the use of detailed Material Take Off (MTO) information.

As the project moves through phases of maturation, the cost estimate should mature in line with the project. As time progresses the base estimate becomes larger as the risk mitigations are incorporated into the design, the contingency becomes less as the risks are understood and engineered out and the cost accuracy improves.

The cost estimate for the Phase 1 activity, the basis of the ACT Acorn project, is a level 4 cost estimate. The later phases of activity are less well defined and are based on previous class 4 estimates that have been scaled or pro-rated for the required project size.
5.3 Cost Summary

5.3.1 Phase 1

Capital costs for Phase 1 of the development include allowances for concept and FEED studies; construction of the onshore capture and compression facilities; acquisition and recommissioning the Atlantic & Cromarty pipeline; construction and installation of the subsea infrastructure, wells and an umbilical. Phase 1 costs, with and without contingency are shown in Table 5-2. More information on the Phase 1 cost estimate can be found in D16 ACT Acorn Full Chain Development Plan and Budget.

Operating costs cover the onshore capture and compression costs, primarily power and chemical makeup; transport and subsea maintenance costs for the operation of the pipeline and subsea infrastructure; and an allowance for subsurface monitoring during the life of the project. The first phase of the project is assumed to have a 20-year operational life.

The abandonment costs for Phase 1 include the onshore capture and compression facilities; the pipeline and umbilical; the subsea infrastructure including the plugging and abandonment of the wells; and a post closure monitoring period. The timing on the abandonment of Phase 1 is dependent on whether the subsequent phases of the project progress. The abandonment of all equipment is assumed to occur at the same time and so Phase 1 would not be abandoned until Phase 2 was no longer operational.

<table>
<thead>
<tr>
<th>Cost Element</th>
<th>Net (£M)</th>
<th>Contingency (£M)</th>
<th>Gross (£M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capex</td>
<td>210</td>
<td>66</td>
<td>276</td>
</tr>
<tr>
<td>Opex</td>
<td>309</td>
<td>32</td>
<td>341</td>
</tr>
<tr>
<td>Abex</td>
<td>25</td>
<td>10</td>
<td>35</td>
</tr>
<tr>
<td>Total</td>
<td>544</td>
<td>108</td>
<td>652</td>
</tr>
</tbody>
</table>

Table 5-2: Phase 1 Cost Summary

5.3.2 Phase 2

The capital cost elements of Phase 2 consist of additional compression modules, wells and infield pipe as required to service the CO₂ supply, as illustrated in Figure 4-5. Depending on the supply profile used there is a provision to acquire and commission the Goldeneye pipeline once the capacity limit has been reached on the Atlantic & Cromarty pipeline. An unallocated provision of 50% has been included on capex elements to cover any incidental costs that have not been defined at this stage of the evaluation. Phase 2 does...
not include any of the costs associated with transporting \( \text{CO}_2 \) to the St Fergus site.

Operating costs in Phase 2 relate to the operation of additional compressors, wells and if it is required the Goldeneye pipeline. The operational costs associated with the Atlantic pipeline are accounted for in Phase 1 while it is operational. Once Phase 1 concludes the Atlantic operational costs are accounted for in Phase 2.

To enable the government to claim back some of the value from the operating payment that was invested in the project in Phase 1 a clawback mechanism is used. Over a 25-year period the clawback allocates a proportion of the revenue to be paid back to the government.

Abandonment costs in Phase 2 relate to the equipment that has been constructed during this phase and includes the compressors, wells and the Goldeneye pipeline if it is required to service the \( \text{CO}_2 \) supply.

<table>
<thead>
<tr>
<th>Cost Element</th>
<th>£million</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capex</td>
<td>373</td>
</tr>
<tr>
<td>Unallocated Provision</td>
<td>187</td>
</tr>
<tr>
<td>Opex</td>
<td>514</td>
</tr>
<tr>
<td>Clawback (53.6% of Revenue, Gov NPV=0)</td>
<td>920</td>
</tr>
<tr>
<td>Abex</td>
<td>31</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2,025</strong></td>
</tr>
</tbody>
</table>

*Table 5-3: Phase 2 cost estimate summary*

5.3.3 Overall Project

The overall project combines Phases 1 and 2. The aggregate costs are shown in Table 5-4 and it should be noted that approximately 50% of the Opex is due to the assumptions of clawback detailed in Table 5-3.

<table>
<thead>
<tr>
<th>Cost Element</th>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capex</td>
<td>276</td>
<td>560</td>
<td>836</td>
</tr>
<tr>
<td>Opex</td>
<td>341</td>
<td>1,434</td>
<td>1,775</td>
</tr>
<tr>
<td>Abex</td>
<td>35</td>
<td>31</td>
<td>66</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>652</td>
<td>2,025</td>
<td>2,677</td>
</tr>
</tbody>
</table>

*Table 5-4: Overall Project Cost Summary*

5.4 Results

The key result measures for the reference case are presented in Table 5-5 and Table 5-6 in real and nominal terms respectively. Results are presented for Phase 1, Phase 2 and the aggregate project.

Cashflow charts for the two project phases and the aggregate project are presented in Figure 5-1.

Analysis of these results are included in the following section.
### Table 5-5: Performance measures (2018 real terms)

<table>
<thead>
<tr>
<th></th>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Project</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>T&amp;S - Real Terms</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre Tax Economic Indicators</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPV</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>£M</td>
</tr>
<tr>
<td>IRR</td>
<td>5.4%</td>
<td>5.4%</td>
<td>5.4%</td>
<td></td>
</tr>
<tr>
<td>PIR</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td><strong>Post Tax Economic Indicators</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPV</td>
<td>-5</td>
<td>-15</td>
<td>-12</td>
<td>£M</td>
</tr>
<tr>
<td>IRR</td>
<td>5.0%</td>
<td>5.0%</td>
<td>5.1%</td>
<td></td>
</tr>
<tr>
<td>PIR</td>
<td>1.0</td>
<td>0.9</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td><strong>Project Spend</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capex</td>
<td>276</td>
<td>560</td>
<td>836</td>
<td>£M</td>
</tr>
<tr>
<td>Opex</td>
<td>341</td>
<td>514</td>
<td>855</td>
<td>£M</td>
</tr>
<tr>
<td>Clawback</td>
<td>0</td>
<td>920</td>
<td>920</td>
<td>£M</td>
</tr>
<tr>
<td>Abex</td>
<td>35</td>
<td>31</td>
<td>66</td>
<td>£M</td>
</tr>
<tr>
<td><strong>Total Cost</strong></td>
<td>652</td>
<td>2,025</td>
<td>2,677</td>
<td>£M</td>
</tr>
<tr>
<td><strong>Project Revenue</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T&amp;S Fee</td>
<td>127</td>
<td>2,774</td>
<td>2,900</td>
<td>£M</td>
</tr>
<tr>
<td>Operating Payment</td>
<td>649</td>
<td>0</td>
<td>649</td>
<td>£M</td>
</tr>
<tr>
<td><strong>Total Revenue</strong></td>
<td>775</td>
<td>2,774</td>
<td>3,549</td>
<td>£M</td>
</tr>
<tr>
<td><strong>Operation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂ Stored</td>
<td>4,218</td>
<td>143,395</td>
<td>147,613</td>
<td>kT</td>
</tr>
<tr>
<td><strong>Unit Costs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂ Storage</td>
<td>155</td>
<td>14</td>
<td>18</td>
<td>£/T</td>
</tr>
</tbody>
</table>

### Table 5-6: Performance measures (2018, nominal terms)

<table>
<thead>
<tr>
<th></th>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Project</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>T&amp;S - Nominal PV Terms</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre Tax Economic Indicators</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPV</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>£M</td>
</tr>
<tr>
<td>IRR</td>
<td>8.0%</td>
<td>8.0%</td>
<td>8.0%</td>
<td></td>
</tr>
<tr>
<td>PIR</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td><strong>Post Tax Economic Indicators</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPV</td>
<td>-8</td>
<td>-20</td>
<td>3</td>
<td>£M</td>
</tr>
<tr>
<td>IRR</td>
<td>7.4%</td>
<td>7.4%</td>
<td>8.1%</td>
<td></td>
</tr>
<tr>
<td>PIR</td>
<td>1.0</td>
<td>0.9</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td><strong>Project Spend</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capex</td>
<td>213</td>
<td>282</td>
<td>495</td>
<td>£M</td>
</tr>
<tr>
<td>Opex</td>
<td>166</td>
<td>131</td>
<td>297</td>
<td>£M</td>
</tr>
<tr>
<td>Clawback</td>
<td>0</td>
<td>307</td>
<td>307</td>
<td>£M</td>
</tr>
<tr>
<td>Abex</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>£M</td>
</tr>
<tr>
<td><strong>Total Cost</strong></td>
<td>382</td>
<td>723</td>
<td>1,105</td>
<td>£M</td>
</tr>
<tr>
<td><strong>Project Revenue</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T&amp;S Fee</td>
<td>62</td>
<td>723</td>
<td>785</td>
<td>£M</td>
</tr>
<tr>
<td>Operating Payment</td>
<td>320</td>
<td>0</td>
<td>320</td>
<td>£M</td>
</tr>
<tr>
<td><strong>Total Revenue</strong></td>
<td>382</td>
<td>723</td>
<td>1,105</td>
<td>£M</td>
</tr>
<tr>
<td><strong>Operation - Discounted</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂ Stored</td>
<td>1,570</td>
<td>22,459</td>
<td>24,029</td>
<td>kT</td>
</tr>
<tr>
<td><strong>Unit Costs - Levelised</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂ Storage</td>
<td>243</td>
<td>32</td>
<td>46</td>
<td>£/T</td>
</tr>
</tbody>
</table>
Figure 5-1: Cashflow charts
5.5 Analysis

5.5.1 Economic Measures

The modelling was designed to achieve a zero NPV on a pre-tax basis, as discussed earlier, and it is clear from Table 5-5 and Table 5-6 that this is the case whether calculated in real or nominal terms. A nominal discount factor of 8% has been used to approximate the cost of capital to finance the project. Inflation is assumed to be 2.5% p.a., resulting in a real discount factor of 5.4%.

On an after-tax basis, the NPVs are slightly negative and thus the IRR measures are also slightly lower than before tax.

The profit investment ratio (PIR) is the \(1 + \frac{\text{NPV}}{\text{discounted capex}}\) and given the basis of the modelling, is by definition 1. This means that 100% of the capital investment is recovered.

Cashflow charts for Phase 1, Phase 2 and the aggregate project are provided as Figure 5-1. It is evident from all three charts that the revenue models result in a long payback time, ranging between 13 and 18 years.

5.5.2 Asset Utilisation

Asset utilisation is significantly different between the phases. In the Phase 1, catalyst, the 200kT/yr uses only 4% of the pipeline whereas in Phase 2, the peak transport and injection rates of 4.5MT/yr represents 90% utilisation of the asset. Similarly, the use of well injection capacity in Phase 1 is 13% whereas in phase 2 it is 100%. The impact of this asset utilisation is a dramatic 91% reduction in the unit costs, as illustrated in Figure 5-2.

Figure 5-2: Comparison of Unit Costs in Real Terms

The impact on levelised cost of transport and storage is very similar and illustrated in Figure 5-3. The analysis shows an 87% reduction from £243/T in Phase 1 to £32/T in Phase 2.
5.5.3 Policy Sensitivity

A sensitivity has been investigated where the UK government has a policy shift away from supporting CCUS projects. In the sensitivity CO₂ storage in Phase 1 stops in 2025 and Phase 2 never begins. Although the Phase 1 capital expenditure will have already been made and there will still be a need to pay the decommissioning costs, the operating expenditure will drop from £341 million to £60 million. The total Phase 1 cost in this case is then £370 million rather than the £652 million in the Reference Case. This sensitivity is intended to illustrate the “regret” costs of committing to Acorn Phase 1 in the relatively near term.

5.5.4 Impact of Development Flexibility

A sensitivity for Phase 2 was developed to evaluate the benefit of adopting a flexible development plan as described in Section 4.4. The sensitivity examines a situation where take up of carbon capture is much more limited than has been assumed in the Reference Case. A CO₂ profile of 1,000kT/yr over the same 38 year period of Phase 2 has been assumed. The total CO₂ stored in Phase 2 is therefore reduced by 73% from 143MT to 38MT.

<table>
<thead>
<tr>
<th>Cost Element</th>
<th>Reference</th>
<th>Low CO₂ Supply</th>
<th>Cost Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capex</td>
<td>560</td>
<td>160</td>
<td>71%</td>
</tr>
<tr>
<td>Opex</td>
<td>514</td>
<td>200</td>
<td>61%</td>
</tr>
<tr>
<td>Clawback</td>
<td>920</td>
<td>267</td>
<td>71%</td>
</tr>
<tr>
<td>Abex</td>
<td>31</td>
<td>7</td>
<td>77%</td>
</tr>
<tr>
<td>Total Cost</td>
<td>2,025</td>
<td>634</td>
<td>69%</td>
</tr>
</tbody>
</table>

Table 5-7: Low CO₂ Supply Sensitivity

In addition to the reduced costs the revenue also decreases from £2,744 million to £762 million and the unit cost of storage increases from £14/T to £17/T. If the government clawback were to remain the same, then a transport and storage fee of £24/T would be required for Phase 2 to have an NPV of zero. In this case the clawback mechanism would only generate £267 million or roughly 40% of the operating payment. A cashflow chart for this sensitivity is provided in Figure 5-4.

The net result in Phase 2 is that a 73% reduction in demand for transport and storage would result in a 69% reduction in the cost, clearly illustrating the benefit of a flexible approach to the build out phase.
5.5.5 Government Perspective

The government return has been calculated as the sum of tax receipts and income from a clawback mechanism.

The clawback mechanism has been designed to achieve an NPV of zero in real terms using a real discount rate of 5.4%. Tax has been calculated as 20% of profit. The clawback mechanism comes into effect at the same time Phase 2 commences and lasts for 25 years.

The operational payment in Phase 1 amounts to £649 million and represents the government investment in the project. To achieve the target zero NPV, the government would need to be paid £9.70/T CO₂ transported and stored. This represents 51% of the total service fee applied by the storage operator and amounts to a total payment of £920 million. Details of the sensitivity are provided in Figure 5-5 and Table 5-8.

### Figure 5-5: Impact of investment recovery on T&S fee

<table>
<thead>
<tr>
<th>Investment Recovery</th>
<th>T&amp;S Fee (£/T)</th>
<th>Clawback (% Revenue)</th>
<th>IRR</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPV Zero</td>
<td>19.3</td>
<td>51%</td>
<td>5%</td>
</tr>
<tr>
<td>Recover 100% of Op Payment</td>
<td>16.9</td>
<td>41%</td>
<td>1%</td>
</tr>
<tr>
<td>Recover 75% of Op Payment</td>
<td>15.5</td>
<td>34%</td>
<td>-2%</td>
</tr>
<tr>
<td>Recover 50% of Op Payment</td>
<td>14.1</td>
<td>25%</td>
<td>-4%</td>
</tr>
<tr>
<td>Recover 25% of Op Payment</td>
<td>12.6</td>
<td>14%</td>
<td>-8%</td>
</tr>
<tr>
<td>No Recovery</td>
<td>11.1</td>
<td>0%</td>
<td>-10%</td>
</tr>
</tbody>
</table>

Table 5-8: Analysis of Storage Fee in Relation to Government Cost Recovery
6.0 Conclusions

1. Phase 1 requires a capital investment of £276 million and an estimated operating expenditure of £341 million over the 20-year evaluation horizon.

2. Phase 1 of the project requires a revenue of approximately £184/T to achieve a zero NPV using an 8% discount rate.

3. A £629 million operating payment from Government has been assumed in Phase 1, along with a service fee of £30/T charged to the CO₂ emitter.

4. The capital and operating costs for Phase 2 are highly dependent upon the level of CO₂ supply and demand for transport and storage services.

5. A transport and storage fee of £19/T enables the build out of the Acorn project in Phase 2 to achieve a zero NPV and the government to recover its investment in Phase 1 via a clawback mechanism.

6. The transport and storage fee required for Phase 2 to become viable is heavily influenced by government cost recovery ranging from £19/T, giving the government a 5.4% internal rate of return, reducing to £12/T if there is no clawback mechanism in place.

7. The unit cost of storage in Phase 2 is 90% less than in Phase 1 and clearly illustrates the economies of scale possible from better asset utilisation.

8. The operational flexibility of the development plan ensures that the costs incurred during Phase 2 are strongly linked to the demand for services. A sensitivity assumed that demand was reduced by 73% and this resulted in a 69% reduction in the costs.

9. The modelling approach to use modular compression units offers an area for improvement. Adding compression units as they are needed with no thought for optimisation or exploiting economies of scale is an area of the modelling work that could be improved upon.

10. The model is a useful tool for considering development options and investigating the impact on infrastructure required based on CO₂ profiles available.

11. While a clawback mechanism has been modelled for simplicity. It is entirely feasible for the government to adopt an alternative method. One example of an alternative to the clawback mechanism is an adaptation of the Contract for Difference used in the power sector. The government could essentially underwrite the costs of the project by guaranteeing a minimum transport and storage fee to the store developer, irrespective of what the current price of CO₂ for the emitter is. In the later stages of the project as the CO₂ price increases the government would receive payments when the CO₂ price is higher than the guaranteed transport and storage fee.
7.0 References


8.0 Annex A – User Guide

The full chain economic model has been constructed in Excel. The various tabs have been used to separate data entry and scenario definition from results and outputs. The model has been constructed to allow for the input of several different scenarios that can be run individually. The model takes advantage of Excel’s built in name manager function to change cell references to make them easier to understand in formulas, as far as possible these names have been included next to the relevant cells.

Control Sheet

The control sheet contains variables that are used to define the basis of the modelling. The scenario is selected on the control sheet as well as other control variables like the base year, rate of inflation, discount rate, etc. Sensitivity variables are also located on the control sheet. These variables are used to change which ranges of cost values are used in the analysis; high, base or low. The sensitivity values also contain flags to use different ranges of prices again; high, mid or low. The control sheet also has a selection of results so that the impact of changing the variables can be seen immediately in both tabulated and graphical forms.

Data Sheet

The data sheet is the main data input for the model. Data can be entered for up to 6 scenarios with low, base and high values for costs. The data entry is split up between cost information for each phase, constraints on operation, government clawback mechanism and a section for constants and conversion factors.

Time Series Sheet

The time series sheet contains input values that change over the course of time, mostly prices. At the top of the sheet the inflation rate and discount rate from the control page are evaluated per year for reference. The next section of the time series page details what the currently in use values are, in both real and nominal terms, for the various prices in use. Below the currently in use section is the data entry for the various price values. Some values have been modelled at a constant price, however this could be replaced with a profile. The final section on the time series page includes data taken from another source, price data for power has been taken from the BEIS energy emissions projections 2017.

Project Sheet

The project sheet contains the cashflow for the overall project pulling in information from the Phase 1 sheet and the Phase 2 sheet. Operational information is shown at the top of the sheet followed by the cashflow in real terms followed by the cashflow in nominal terms.

Phase 1 Sheet

The Phase 1 sheet uses the inputs from the data sheet and the time series in conjunction with calculations in the operations sheet to model the economics of Phase 1. The sheet has a summary of the operations data needed for the economic evaluation at the top of the sheet. Below the operational information are the cashflow calculations in real terms. This includes the elements of capex, opex, abex and tax calculations. The cashflow calculations are also shown in nominal terms.
Phase 2 Sheet

The Phase 2 sheet is set up in the same way as the Phase 1 sheet only pulling in the cost and operational data for Phase 2 instead.

Government Sheet

The government sheet pulls in information to display the government view of the project. The outgoings being the operational payment to Phase 1 and income from tax receipts and the clawback mechanism in Phase 2. Again, this sheet shows calculations in both real and nominal terms.

Operations Sheet

The operation sheet contains the calculations for the required number of wells, compressors and whether or not the Goldeneye pipeline is required. These calculations are based on the CO₂ profiles used. The Phase 2 profile is pulled in from either D02 Scenario A or D02 Scenario B depending on what is selected on the control sheet. This profile is constrained based on the storage limit that is entered on the Data sheet. The logic that determines whether a source is included or not simply looks at the amount of space remaining in the store and whether the entire inventory of emission will fit in the store. The constrained profile is then analysed to determine how many modules of compression are needed using the information supplied on the Data sheet. The model then checks if the Goldeneye pipeline is required based on the Atlantic pipeline throughput capacity. The CO₂ profiles in each pipeline are then used to determine how many wells are required based on the injectivity limit set in the constraints on the Data sheet.

D02 Scenario A Sheet

The D02 Scenario A sheet contains a copy of the profiles that were developed in D02 as a reference.

D02 Scenario B Sheet

The D02 Scenario B sheet contains a copy of the profiles that were developed in D02 as a reference.
9.0 Annex B – Detailed Model Inputs

Control Sheet

<table>
<thead>
<tr>
<th>Project</th>
<th>ACT Acorn</th>
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<tbody>
<tr>
<td>Client</td>
<td>BEIS</td>
</tr>
<tr>
<td>Revision</td>
<td>V1</td>
</tr>
<tr>
<td>Date</td>
<td>14/05/2018</td>
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</tbody>
</table>

Acorn Economic Model

Economic Model of the ACT Acorn Project and Build Out

Control Variables

- **Name**: Scenario, Phase 2 Scenario, Base Year, Tax Rate, Tax Paid in Year, Inflation, Nominal Discount Rate, Real Discount Rate
- **Value**: Scenario, Basic_C02, 2018, rate_tax, rate_paid, rate_inf, rate_disc
- **Selected**: 1 Base Case, Acorn A

Sensitivity Variables

- **Name**: T&S Cost, SMS Cost, Well cost, Compression cost, Goldeneye Pipeline Cost
- **Value**: uct_Store, uct_SMK, uct_well, uct_comp, uct_Gap

Timing

- **Phase 1 Start**: start_P1
- **Phase 2 Start**: start_P2

Build Description

- **Phase 1**: Base ACT Acorn Project
- **Phase 2**: Build Out Vision
- **Building**: Storage of 200kT/y CO2 from St Fergus in a single subsea well
- **Build Out Vision**: Additional CO2 captured and sent to St Fergus according to scenarios in D02

T&S - Real Terms

- **NPV**: 0 £M
- **IRR**: 5.4%
- **Pir**: 2.5%

Post Tax Economic Indicators

- **NPV**: -5 £M
- **IRR**: 5.0%
- **Pir**: 2.5%

Project Spend

- **Capex**: 276 £M
- **Opex**: 341 £M
- **Clawback**: 0 £M
- **Alres**: 35 £M

Total Cost

- **2,635 £M

Project Revenue

- **T&S Fee**: 127 £M
- **Operating Payment**: 649 £M

Total Revenue

- **2,446 £M

T&S - Nominal PV Terms

- **NPV**: 0 £M
- **IRR**: 8.0%
- **Pir**: 3.0%

Pre Tax Economic Indicators

- **NPV**: 0 £M
- **IRR**: 8.0%
- **Pir**: 1.0%

Post Tax Economic Indicators

- **NPV**: -8 £M
- **IRR**: 7.4%
- **Pir**: 1.0%

Project Spend

- **Capex**: 213 £M
- **Opex**: 266 £M
- **Clawback**: 0 £M
- **Alres**: 3 £M

Total Cost

- **2,825 £M

Project Revenue

- **T&S Fee**: 62 £M
- **Operating Payment**: 320 £M

Total Revenue

- **382 £M

Cumulative Injection (MT)

- **2018**: 500 MT
- **2020**: 1,000 MT
- **2022**: 1,500 MT
- **2024**: 2,000 MT
- **2026**: 2,500 MT
- **2028**: 3,000 MT
- **2030**: 3,500 MT
- **2032**: 4,000 MT
- **2034**: 4,500 MT
- **2036**: 5,000 MT

Cumulative Injection (MT)

- **2018**: 0 MT
- **2020**: 500 MT
- **2022**: 1,000 MT
- **2024**: 1,500 MT
- **2026**: 2,000 MT
- **2028**: 2,500 MT
- **2030**: 3,000 MT
- **2032**: 3,500 MT
- **2034**: 4,000 MT
- **2036**: 4,500 MT

Cumulative Injection (MT)

- **2018**: 0 MT
- **2020**: 500 MT
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- **2024**: 1,500 MT
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- **2028**: 2,500 MT
- **2030**: 3,000 MT
- **2032**: 3,500 MT
- **2034**: 4,000 MT
- **2036**: 4,500 MT

Cumulative Injection (MT)

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- **2020**: 500 MT
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- **2024**: 1,500 MT
- **2026**: 2,000 MT
- **2028**: 2,500 MT
- **2030**: 3,000 MT
- **2032**: 3,500 MT
- **2034**: 4,000 MT
- **2036**: 4,500 MT

Cumulative Injection (MT)

- **2018**: 0 MT
- **2020**: 500 MT
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- **2024**: 1,500 MT
- **2026**: 2,000 MT
- **2028**: 2,500 MT
- **2030**: 3,000 MT
- **2032**: 3,500 MT
- **2034**: 4,000 MT
- **2036**: 4,500 MT

Cumulative Injection (MT)

- **2018**: 0 MT
- **2020**: 500 MT
- **2022**: 1,000 MT
- **2024**: 1,500 MT
- **2026**: 2,000 MT
- **2028**: 2,500 MT
- **2030**: 3,000 MT
- **2032**: 3,500 MT
- **2034**: 4,000 MT
- **2036**: 4,500 MT

Cumulative Injection (MT)

- **2018**: 0 MT
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- **2024**: 1,500 MT
- **2026**: 2,000 MT
- **2028**: 2,500 MT
- **2030**: 3,000 MT
- **2032**: 3,500 MT
- **2034**: 4,000 MT
- **2036**: 4,500 MT

Cumulative Injection (MT)

- **2018**: 0 MT
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- **2032**: 3,500 MT
- **2034**: 4,000 MT
- **2036**: 4,500 MT

Cumulative Injection (MT)

- **2018**: 0 MT
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- **2026**: 2,000 MT
- **2028**: 2,500 MT
- **2030**: 3,000 MT
- **2032**: 3,500 MT
- **2034**: 4,000 MT
- **2036**: 4,500 MT

Cumulative Injection (MT)

- **2018**: 0 MT
- **2020**: 500 MT
- **2022**: 1,000 MT
- **2024**: 1,500 MT
- **2026**: 2,000 MT
- **2028**: 2,500 MT
- **2030**: 3,000 MT
- **2032**: 3,500 MT
- **2034**: 4,000 MT
- **2036**: 4,500 MT
## Data Sheet

### Phase 1 - Base Acorn Development Cost

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<tr>
<th>Description</th>
<th>Name</th>
<th>Selected Units</th>
<th>Low</th>
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<th>High</th>
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<tr>
<td>Design Life</td>
<td>TNS_Life</td>
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<td>PC MMV Period</td>
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<td>CO2 Supply Rate</td>
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### Operation

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<td><strong>Total</strong></td>
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### Opex

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<th>Subsurface Monitoring</th>
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### Abex

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<td>Post Closure</td>
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<td><strong>Total</strong></td>
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<td>37.2 £m</td>
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### Phase 2 - Build Out

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<tr>
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<tr>
<td>Unallocated Provision</td>
<td>UP_well</td>
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<td>50%</td>
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<table>
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<td>Opex</td>
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<tr>
<td>Abex</td>
<td>abx_IP</td>
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<tr>
<td>Unallocated Provision</td>
<td>UP_IP</td>
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<tr>
<th>Compression</th>
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<tr>
<td>Duty</td>
<td>comp_duty</td>
<td>0.05 MWh/TCO2</td>
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<td>Rating</td>
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<td>6.6 MW</td>
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<td>Throughput</td>
<td>comp_through</td>
<td>527 kT/CO2</td>
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<th>Goldeneye Pipeline</th>
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<td>Abex</td>
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<td>Unallocated Provision</td>
<td>UP_Gep</td>
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<tr>
<th>Constraints</th>
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<td>Atlantic Pipeline Capacity</td>
<td>cap_ACP</td>
<td>5,000 kT/y</td>
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<tr>
<td>Goldeneye Pipeline Capacity</td>
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<td>4,000 kT/y</td>
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<td>Max Injection Rate per well</td>
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<td>Well Lifespan</td>
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<td>Store Capacity</td>
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<thead>
<tr>
<th>Government</th>
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</thead>
<tbody>
<tr>
<td>Clawback on Revenue</td>
<td>Clawback</td>
<td>50.8%</td>
<td>50.8%</td>
</tr>
<tr>
<td>Clawback Period</td>
<td>CB_Period</td>
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<td>Grant Award</td>
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<td>Grant Timing</td>
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## Time Series Sheet

### General Rates

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<th>Unit</th>
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<tr>
<td></td>
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<tr>
<td>Inflation</td>
<td>2.50%</td>
</tr>
<tr>
<td>Discount</td>
<td>8.00%</td>
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### In Use

#### Real

- **Phase 1 T&S Fee**
  - E/T: 30.00 30.00 30.00 30.00 30.00 30.00 30.00 30.00 30.00 30.00 30.00 30.00 30.00 30.00 30.00 30.00 30.00 30.00 30.00
- **Phase 2 T&S Fee**
- **Operational Payment**
- **Power Price**
  - E/MWh: 46.20 46.00 46.82 47.56 48.28 49.51 51.19 52.12 51.07 55.02 55.66 55.20 60.30 60.92 55.71 55.56 55.82 44.69
- **Carbon Price floor**

#### Nominal

- **Phase 1 T&S Fee**
  - E/T: 30.00 30.75 31.52 32.31 33.11 33.94 34.79 35.66 36.55 37.47 38.40 39.36 40.35 41.36 42.39 43.45 44.54 45.65
- **Phase 2 T&S Fee**
- **Operational Payment**
  - E/T: 153.85 157.70 161.64 165.68 169.82 174.07 178.42 182.88 187.45 192.14 196.94 201.87 206.91 212.09 217.39 222.82 228.39 234.10
- **Power Price**
  - E/MWh: 46.20 47.15 49.19 51.22 53.30 56.02 59.36 61.96 62.22 68.72 71.25 72.43 81.09 83.98 78.72 80.46 82.87 68.00
- **Carbon Price floor**
  - E/T: 4.08 4.37 4.68 5.00 5.32 7.11 11.52 15.32 21.19 29.49 35.99 42.22 51.71 53.00 54.32 55.68 57.07 58.50

### Price Ranges

#### Phase 1 T&S Fee

- **Low - £25/T**
  - E/T: 25.00
- **Mid - £30/T**
  - E/T: 30.00
- **High - £35/T**
  - E/T: 35.00

#### Phase 2 T&S Fee

- **Low - £15/T**
  - E/T: 15.00
- **Mid - £19/T**
  - E/T: 19.34
- **High - £25/T**
  - E/T: 25.00

#### Operational Payment

- **Low - £50/T**
  - E/T: 50.00
- **Mid - £54/T**
  - E/T: 53.85
- **High - £60/T**
  - E/T: 60.00

#### Power Price

- **Low - £40/MWh**
  - E/MWh: 39.58
- **Mid - £46/MWh**
  - E/MWh: 46.20
- **High - £56/MWh**
  - E/MWh: 55.57

#### Carbon Price Floor


---

**ACT Acorn Consortium**

Page 38 of 39
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
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| Capex Phasing | 0.1 | 0.3 | 0.6 |