Programme Area: Carbon Capture and Storage

Project: Scoping New Thermal CCS Power Station

Title: Incentivisation of Thermal Power with CCS – Stage 1B Final Report

Abstract:

The Energy Technology Institute (ETI) is charged with promoting low carbon technologies – to develop them and ease their implementation. In this regard, the ETI commissioned Pöyry to develop a model and an accompanying report with the primary objective of understanding the risks involved in implementation of future Carbon Capture and Storage (CCS) projects, and hence assessing their economic viability. The model, developed for the project and supplied to ETI, is designed in Excel with the functionality to adjust input parameters for the purpose of updating and improving model accuracy as the market evolves and new information on CCS projects becomes available.

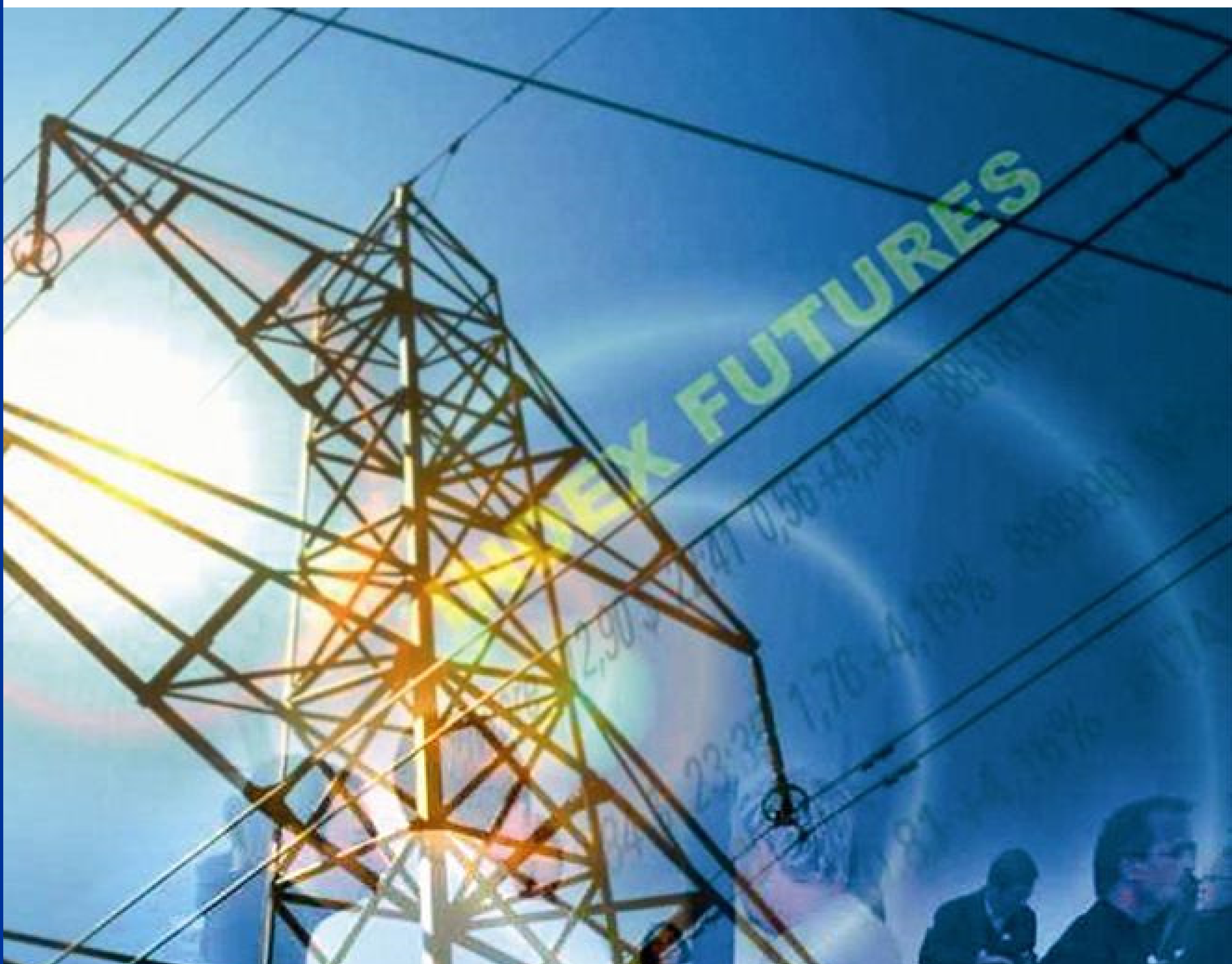
Context:

The aim of this project was to scope out a potential ETI Project which would establish an investment proposal for a new, GW scale, carbon-abated, thermal power station, which minimised risk and built on infrastructure which was at the time being proposed in response to the DECC CCS Commercialisation Competition. This scoping exercise had two major components: a review of potential sites where such a station might be built, taking into account existing infrastructure and planned CO2 transport and storage infrastructure; and the development of an investment model to identify the key features of an investable CCS power project. The ETI's ultimate objective was to establish a new investment consortium ready to undertake 'front-end engineering design' (FEED) on a major thermal power station development incorporating CCS (£2bn+ capex). This initial scoping project sought to create a clear view of the structure of that future FEED study, the likely shape of the power project and to identify potential partners.

INCENTIVISATION OF THERMAL POWER WITH CCS - STAGE 1.B FINAL REPORT

A report to the Energy Technology Institute

14 November 2014



INCENTIVISATION OF THERMAL POWER WITH CCS - STAGE 1.B FINAL REPORT

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EXECUTIVE SUMMARY

The Energy Technology Institute (ETI) is charged with promoting low carbon technologies – to develop them and ease their implementation. In this regard, the ETI commissioned Pöyry to develop a model and an accompanying report with the primary objective of understanding the risks involved in implementation of future Carbon Capture and Storage (CCS) projects, and hence assessing their economic viability. The model, developed for the project and supplied to ETI, is designed in Excel with the functionality to adjust input parameters for the purpose of updating and improving model accuracy as the market evolves and new information on CCS projects becomes available.

Project methodology

Primarily, the project was split into two stages:

- **Stage 1.a**, identification of components and allocation of risk for three archetypal CCS projects assumed to be reaching FID in the early 2020's; and
- **Stage 1.b**, development of a risk adjusted Levelised Cost of Electricity (LCOE) model for each of the aforementioned projects.

Stage 1.a

For **Stage 1.a** of the project Workshop 1 with ETI yielded a risk categorisation strategy deconstructed into three primary components:

- Financier Risk Categories – these are various risk areas that a financier would consider when making an investment decision in a large energy sector project;
- Risk Building Blocks (and their Sub-categories) – these are characteristics of a CCS project, which are important to define and differentiate that project in terms of its cost and revenue riskiness; and
- Risk conduits – link by which a project characteristics (Risk Building Blocks) would influence the financier's perception of risk (the Financier Risk Categories).

Subsequently the risks for each category were quantified using a questionnaire designed to identify prevailing expectations of risk within ETI. Although this approach is somewhat subjective, the questionnaire parameters were designed to give a realistic indication of the magnitude of potential risks based on current market expectation. These values could then be used to create a 'base-case' (P50) and 'downside-case' (P90) scenario for three archetype projects (Projects A, B, and C) spanning a range of risk levels. The volatility was then translated into a risk score and output to a colour coded chart allowing comparison of the risk attributes of the Archetypal projects.

Stage 1.b

Stage 1.b was designed to incorporate risk into a standard LCOE model by comparing P90/P50 LCOE values for our CCS Archetypes to recent energy projects with known volatility of returns. By regressing data on revenue volatility and required Rates of Return (RoR) for recent known projects (and other research), we were able to derive a relationship between P90/P50 LCOE volatility ((P90/P50 ratio) and required RoR for use in the model. This rate, which varies by project based on its return volatility (i.e. risk), is fed into the LCOE equation and a final risk-adjusted LCOE is calculated. The output value from the modelling can then be used to compare each of the Archetype project's economic viability.

Key findings

Table 9 below shows a summary of the project results for our Archetypal Low risk (Project A), Medium risk (Project B) and High risk (Project C) projects, taken from the Output sheet of the Risk Weighting LCOE model.

Table 1 – Summary of expected LCOE values for the Archetypal Projects

LCOE Summary Output table	Expected P50 LCOE (£/MWh 2013 money)		
Discount Rate	Project A - Aire Valley	Project B - Humber Estuary	Project C - North-east England
LCOE for Low Risk Rate [7.5%]	98.5	78.5	80.8
LCOE for Flat Rate [10%]	110.5	84.1	91.3
Risk Adjusted Discount Rate	9.0%	11.3%	21.9%
LCOE @ Risk Adjusted Discount Rate	105.7	87.3	158.4
Risk adj. Vs Flat Rate Ratio	**0.96**	**1.04**	**1.73**

Our low risk archetypal project, Project A, is the poorest performing project on a flat discount rate comparison. Therefore, on a simple LCOE analysis, it may be the least likely of our archetypal projects to realise project implementation. However, this comparison excludes the reality that higher discount rates would be required to attract finance for projects with a greater element of risk. Project A is defined as a low risk project based on a relatively established technology and feeding into a pre-existing transport and storage system. Therefore, the calculated discount rate is favourable in comparison to the alternative projects. Consequently, the risk adjusted LCOE is more favourable for Project A than that of Project C despite having a much higher LCOE value at both 10% and 7.5% discount rates.

Project B has the lowest P50 LCOE assuming a flat 10% discount rate and, ignoring risk, may be considered generally more attractive than the alternative archetypal projects given the assumptions on capital and operational costs. Indeed even after accounting for its higher risk nature, Project B is still more attractive than Project A – this is partly a construct of the estimated costs but it also partially attributable to Project B being a gas based CCS plant. Megawatt for megawatt, the cost of building a gas fired power station is significantly lower than the costs involved in building a coal power station. As the discount rate exclusively affects the capex component of the LCOE equation, Project B is therefore less sensitive to an adjusted discount rate than an equivalent scale coal plant. The stable capex component of Project B, coupled with the project's already economically favourable specifications results in the risk adjusted LCOE being significantly lower than projects A and C.

Our archetypal high risk project, Project C, is the economically optimal project choice given a 7.5% discount rate using P50 values. However, the high level of risk involved in the project results in a significantly higher risk-adjusted discount rate, hence a substantially inflated risk-adjusted LCOE. The discount rate adjustment required is significantly higher than the medium/low risk projects with Project C demanding a discount rate of over double that of Project A. This is due in part to the non-linear nature of project risks (as shown in our survey results) but also due to the compound nature of certain project risks and their feed through into the P90 LCOE calculation.

Concluding Remarks

Although this project has been focused on valuing risk, we have seen that while the P90/P50 ratio (which we are using as a proxy for that risk) is a major driver of the LCOE, it should not be the only consideration. Some decisions to drive down cost with only minor risk impacts (or where risks can be well mitigated) may well be 'worth it' to lower overall strike prices (evidenced by the LCOE of Project B, our medium risk project).

In addition, the available funding for projects of different risk/reward ratios is variable meaning that the overall capital cost of the project is an essential further consideration for project developers and policy designer. Indeed where the underlying risk is inherently high, such as when developing a new CCS cluster, taking a low capital cost approach to the capture side could have material additional benefits in terms of strike prices.

However it should also be noted that the results shown in this section are simply examples of the way in which the model can be used rather than an end point in themselves. In reality any new project being examined is likely to look like a combination of the choices for the three archetypal projects (rather than being an archetypal High/Medium/Low project itself). To date, the model has been populated with the three projects to illustrate the tool but it can be populated with real life project examples and used in other ways by ETI in the future. For example one alternative use of the model would be to use it to indicate potential key steps required to get a project category from a High risk to a Low risk score, and to estimate the value in doing so.

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1. INTRODUCTION

The ETI is charged with promoting low carbon technologies – to develop them and ease their implementation.

ESME modelling has shown that CCS is the most regret low-carbon technology if it fails to be widely deployed: apart from the direct impact on power sector emissions, it also has potential to capture emissions from industrial sources, and to link into hydrogen-based energy systems. So there is a strong rationale for the ETI taking specific actions to promote CCS development.

DECC's main focus is delivering the first two CCS projects – they are currently carrying out FEED studies, which will among other things evaluate the lifetime generation cost.

The CCS Cost Reduction TaskForce (CRTF) showed how significant cost reductions are feasible for CCS from the early projects as later ones are built. This is because of straightforward reductions in a more mature capture technology; benefitting from a more developed transport and storage infrastructure and having access to lower cost finance in a comparable way to other mature technologies.

Other parts of the world have also experienced similar delays and slow implementation to the UK – although arguably now some projects in Canada and the US are likely to be among the first fully integrated CCS power plant in operation.

Whilst focussing on the FEED studies, DECC is working with a number of potential projects, which might form part of the first wave of follow-on projects. However, many of these are a result of historical initiatives. Originally the "competition" for CCS project funding was limited to "post-combustion" coal-fired projects, but the latest one was widened out to include pre-combustion gasification-type projects and gas-fuelled ones as well. Furthermore, the very nature of the competition has required each submission entry to be treated in isolation, with no scope at all for combining aspects of different entries to optimise further.

ETI is now interested in taking practical steps to facilitate implementation of a low risk follow-on project, and this is the main objective of the wider work into which this project will feed. Timescales for the work are driven somewhat by the need to have firm proposals ready to move as the FEED studies complete, and that therefore the ETI will need to be in a position to approve this project at a Board meeting before the end of the year.

1.1 Project work plan

The project divides into three Stages:

Stage 1.a: Project level risk assessment to define the building blocks of the project and develop a comparative risk assessment score;

Stage 1.b: Building a Risk Adjusted Energy Cost Model to produce a 'first cut' of required CfD strike prices; and

Stage 2: Financial Model construction and project evaluation to provide a fully populated and editable financial model to ETI to estimate required CfD FiT strike prices.

The current contract covers Stages 1.a and 1.b only.

The remaining Chapters set out findings of Stage 1.a and Stage 1.b of the project in more detail:

- Chapter 2 sets the context of the Project and the process followed to date;
- Chapter 3 provides a functional description of the Risk Adjusted LCOE Model (i.e. Deliverable D1.3 under Stage 1.b);
- Chapter 4 describes the risk allocation and risk ratings of the three shortlisted archetypal projects;
- Chapter 5 provides an overview of the key Risk Adjusted LCOE model results for the shortlist of archetypal projects; and
- Chapter 0 provides a high level view of the Financial Model, which would be delivered under Stage 2 of the project.

An Excel-based Risk Weighting LCOE Model accompanies the report.

This Report (the "Final Report", or Deliverable D1.2) together with the delivery of the excel-based Risk Weightings Model, which accompanies the delivery of this document is the conclusion of the Stage 1.b Phase of the project.

1.2 Sources and assumption

Unless otherwise attributed the source for all tables, figures and charts is Pöyry Management Consulting.

All monetary values are quoted in Great British Pounds (£/GBP) and are in real 2013 money unless otherwise stated.

2. CONTEXT OF THE PROJECT

Stage 1 of the project has been divided into two parts: Stage 1.a – Project level risk assessment and Stage 1.b – Building a Risk Adjusted Energy Cost Model. Together the key focus of these elements was to build a coherent picture and evaluation framework for the risks associated with development of an individual CCS project. The key outputs from the work are this report, and a model with which ETI can quantitatively evaluate alternative CCS projects from an investor's point of view.

The concepts of 'investability' or 'financeability' are often quoted, but are not always well defined. Generally one can say that a project is more investable if it can attract lower cost forms of finance, but this needs to be underpinned by a lower level of risk (either downside risk and/or overall expected returns). In addition, there is a boundary to the acceptable risks[1] beyond which sufficient finance simply cannot be obtained – beyond this the project would then become unfinanceable.

Many elements peculiar to CCS projects, both internal and external, can affect the risk beyond that of a normal thermal power station investment, for example:

- Maturity of chosen capture technology;
- Location of project (both between countries, but also within a country);
- Scale and type of support mechanism available;
- Pre-existing vs new pipeline; and
- Proven vs. unproven storage resource.

It should be noted that any project to quantify risk in the CCS sector will be subject to a high degree of subjectivity due to its developmental state. For example the lack of representative data on cost overruns, efficiency, availability characteristics etc. for large scale CCS projects from which to work, will necessitate a reliance on inter-technology comparisons and the skill, judgement and experience of project staff. While this uncertainty is unavoidable it does not, in our view, diminish the value of the process. This is particularly the case where the results of the work can be made more widely available to spark debate and enhance the understanding of other stakeholders in the industry.

The challenge to develop the model in an efficient and useable way is to have sufficiently explored the nature and magnitude of the risks (and sources/evidence to support them) before embarking on detailed model design and construction. With this in mind, we undertook substantial early efforts, involving the ETI team and wider stakeholders, to bottom out the most important project risks and design building blocks of the model to suitably reflect this.

Over the course of the project, four Workshops were held – the first with only ETI participants and the second with a range of delegates to add technical and project developers' perspectives. Workshop 3 and the final phase were focussed on designing, building and testing the detailed risk-weighting approach for the LCOE calculation. The work concluded with the delivery of the model and a final meeting with ETI and key stakeholders. These stages of work along with key principles are briefly described in turn below.

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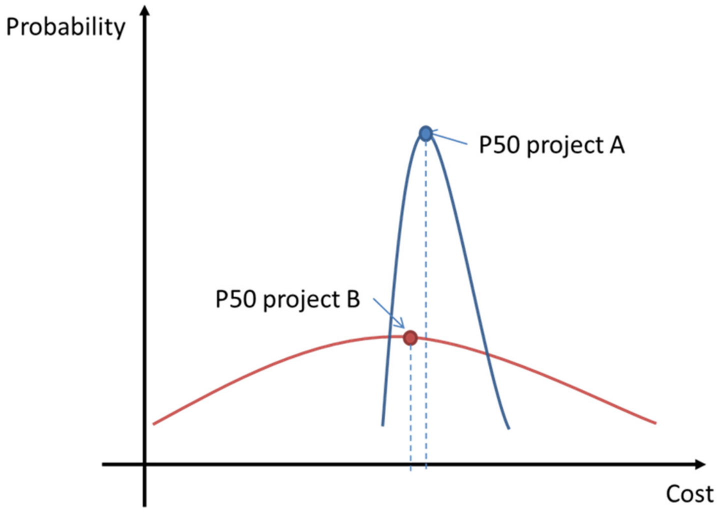
1 This is inclusive of duration of risk over various stages of a project life cycle and absolute levels of risk.

2.1 Workshop 1: Risk building blocks

The main aim of the first workshop was to develop and refine the concept of Risk Building Blocks. Understanding the main sources of risk is fundamental to the way in which investors will view projects: it is quite possible that a project with a somewhat higher P50 view of cost will be more attractive to investors because of the lower risks of a substantial project overrun (characterised by a tighter distribution around the P50 value resulting in tighter confidence intervals), as illustrated in the chart below:

Figure 1 – Probability-based Distribution of project costs



Our approach to the problem of differential overrun potential between projects is to develop a set of "Building Blocks" that are uniquely definable project characteristics that differentiate the project in terms of risk. These may well be physical characteristics of the planned project, but could also be contractual, planning, political or even 'developer capability" based.

It is important for both developers and investors to fully understand the risks associated with different types of investments. It is typical for an developer seeking internal approval or external finance to create a model examining projected returns for a range of scenarios. These scenarios will always consist of at least a 'base-case' (usually a P50 case) and 'downside-case' (usually a P90 case or something similar).

Within the energy industry relevant risks vary between technology types. For example, in the case of an offshore wind project one of the key driving factors for revenues would be wind yield, which, given a P50 case would yield the expected revenues for a given project. Cutting this wind yield to only include that which falls within the 90% confidence interval has a drastic effect on the plants overall profitability. Looking at a CCGT however, wind patterns are largely irrelevant, and instead exposure to gas market prices becomes a heavily contributing factor for quantifying risk. Developers and investors faced with quantifying the risks for a given project will always need to tailor their models for the specific project. The "Risk Building Blocks" methodology stems from this necessity to incorporate the relevant risk components for a CCS project.

During the course of the Workshop it was agreed that we would not include pre-FID issues such as consenting in core modelling efforts, because the FID would only be taken after such critical issues have already been completely cleared.

It was decided to take forward four overarching building blocks:

- Siting & engineering design risks (physical elements of the project chosen site, engineering and design, which typically must be decided early on in the process).
- Processes, operation and monitoring risks (physical elements of the project which form choices on the operation of the plant itself, but do not necessarily need to be decided before FID).
- Ownership, contractual and consenting risks (generally non-physical attributes of the project related to the developer, management, legal or political considerations.)
- Other (any other risks as they arise to capture wider issues for CCS developers).

After minor refinements, these were then carried forward into the Second Workshop, which considered how to weight the risks and consider the risks from a financiers perspective.

2.2 Workshop 2: Risk Weighting

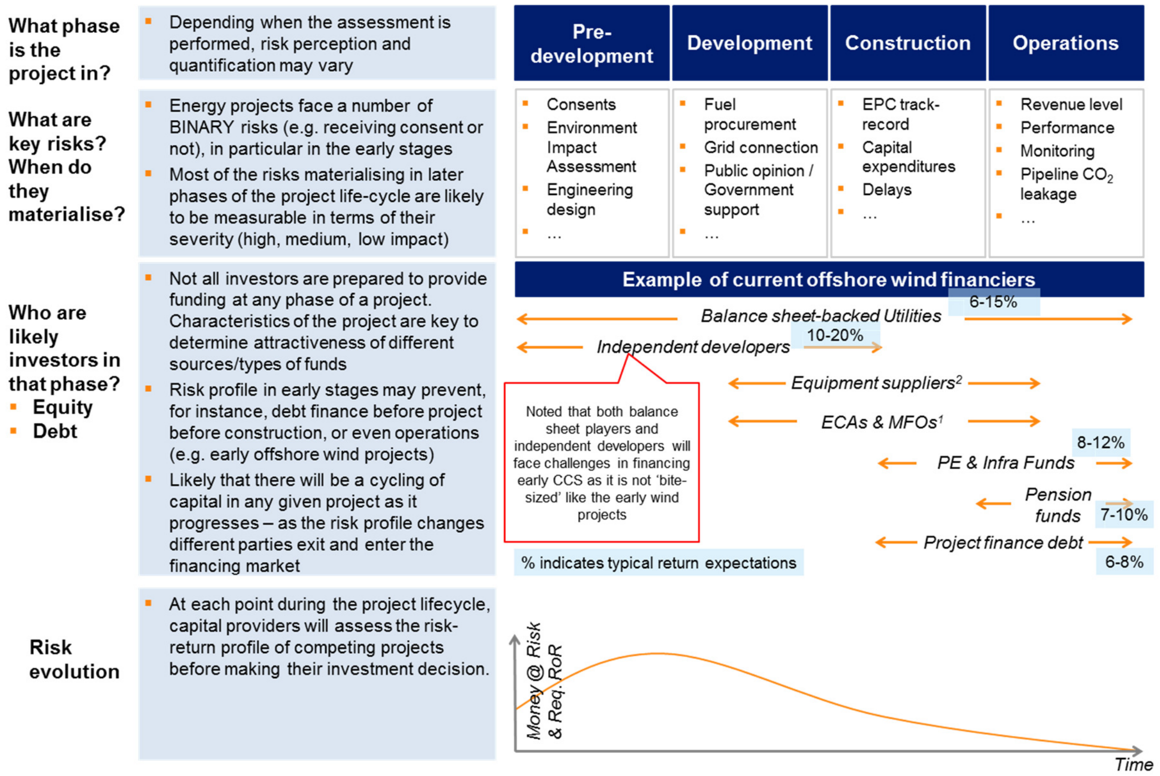
The objective of the second Workshop was to take the risk building blocks and develop the theme of Risk Conduits; these are the routes by which a particular building block will influence costs[2] and hence a financiers perception of risk (e.g. choice for Capture Technology Building Block will influence likelihood and scale of capital cost overruns).Any particular building block may have multiple conduits – i.e. many ways in which it influences the expected returns/debt repayment ability of the project (e.g. Capture Technology choice will also influence risk of opex overruns and lower plant availability).

An example of the risk assessment process for a typical offshore wind financing was discussed to give some context for future work. This process is shown in Figure 2 below. The key elements discussed include the need to understand the process by which the project risks will vary with the project phase and therefore the different investor types that we would expect to see entering and exiting projects over its lifetime.

It was also noted that whilst some useful lessons for CCS can be learned from examining other technologies, CCS has some unique properties which increase the complexity of the financing. This will include the introduction of different kinds of risks (particularly those associated with cross chain elements) but also that the 'lumpy' nature of CCS projects will creates large capital cost requirements compared to the more bite sized wind market. Lower capital cost projects have the potential advantage that, all other things being equal, they should be somewhat easier to finance in a capital constrained world.

2 Therefore, for a given CfD strike price would influence project returns.

Figure 2 – Overview of risk and financeability of energy projects



1. insurance companies, Export Credit Agencies (ECAs) and multilateral financial organisations (MFOs)
2. Equipment suppliers, ECAs & MFOs do not typically invest on the same risk/return basis – the return comes from development of a future market

There is no definitive structure for describing Financier Risk Categories[3] – a significant part of the Workshop was spent discussing the starting list below:

- Construction risk;
- Technology risk;
- Operational risk;
- Ownership & Contractual risk;
- Policy & Regulatory risk; and
- Permitting & Consent risk.

One of the decisions taken in the workshop was to omit the Permitting & Consent category from the later LCOE modelling, because at FID these will have disappeared – without them being completely certain no FID would be taken.

3 The 'Financier Risk Categories' are the various risks that a financier would consider when making an investment decision as opposed to the 'Building Blocks' which are the characteristics of a project which define and differentiate a project in terms of investment riskiness. These two concepts are linked by the 'Risk Conduits' as explained in section 3.4.

The majority of the workshop was spent defining the risks of the sub-categories in more detail – for example what, on a block by block level, might P90 cost and/or time overruns be for a 'Low', 'Medium' and 'High' risk project.

2.3 Workshop 3 and model development

The third meeting (Workshop 3) was built around a Q&A session about the deliverables of the interim phase Stage 1.a. It specifically aimed at ensuring that the content of the Interim Report was appropriate and that the mechanics of the Risk Weightings Model were clearly understood by the potential business users within the ETI team.

The final phase of the project then focussed on designing a detailed risk-weighting approach for the LCOE calculation and on upgrading the functionalities of the model accordingly (see description in Chapter 3 of this report).

2.4 Workshop 4

At the completion of the final phase a fourth workshop was held in which Pöyry presented the final phase model and key findings detailed in the final phase report. This workshop discussed the final phase deliverables and feedback from ETI was provided for integration into the final deliverables.

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3. RISK ADJUSTED ENERGY COST MODEL (STAGE 1.B)

This chapter explores the principles and functionalities of the Risk Adjusted Energy Cost (or LCOE) Model developed for ETI. The Risk Adjusted LCOE model has been developed as an extension of the Risk Weighting Model delivered as part of Risk Allocation of Shortlisted Projects (Stage 1.a) of this work and is similarly structured.

Section 3.1 states the objective of the risk scoring exercise leading to the initial project ranking. We then describe in more detail the elements composing the model (Section 3.4). Finally, we explain its structure and functionalities, both from a methodological and operational perspective (Section 3.5).

3.1 Overall objective

The Model aims to structure the risk assessment around the Building Blocks of a CCS project, as jointly identified by ETI and Pöyry, and at yielding an internally-consistent framework to differentiate between projects in terms of risk.

Based on a number of input assumptions, and intermediary calculations, the original Stage 1.a produced a weighted 'risk score' by key category of risk which can be then turned into a risk ranking of selected CCS projects. In Stage 1.b we have extended the model to produce a single risk-weighted LCOE figure (as a first cut or proxy for a required CfD strike price). The model contains data for three 'archetype' projects. The model can, however, be used to estimate the LCOE for any potential project of a similar type, provided the necessary project parameters (inputs) are available. This can be done using the generally applicable guidance/criteria within the model.

3.2 What does LCOE mean?

3.2.1 Definition

The levelised cost of energy (LCOE) is a simplified metric widely used in the energy industry to compare different projects (or technologies) based on the combination of their capital, operations & maintenance and fuel costs as well as performance (e.g. availability, dispatch, efficiency). It is a standardised measure that does not explicitly consider how a project is financed or how risk is allocated between parties.

In financial terms, the LCOE is an average *value* (e.g. GBP per MWh) that would have to be charged for electricity over a project's economic lifetime such that the Net Present Value (NPV) of all cash flows over this lifetime, at the assumed discount rate (r), equals zero. Looking at this from an investor's perspective, "r" is the equivalent to the minimum required rate of return to the investors.

3.2.2 Formula & inputs

3.2.2.1 Simplified approach

Instead of building a full-blown financial model, the LCOE of a specific project can be calculated by using a simplified formula approach. The result of this formula is, from a conceptual point of view, the minimum unit value of generation that makes a project break even on its cost.

The LCOE formula is defined as follows:

*LCOE = [(Capex * CRF) + Fixed Opex] / (8,760 * Capacity Factor) + Variable Cost*

where:

- Capex: initial capital investment
- Fixed Opex: fixed O&M cost on a GBP per year basis
- Variable Cost: other variable O&M, carbon and fuel cost, including (as a negative cost) assumed EOR or other 'secondary' revenues apart from electricity sales on a GBP per MWh basis
- Capacity Factor: percentage of time that the plant runs at full capacity over a year
- CRF is the capex recovery factor that accounts for the build time and annualises the capital investment over the project lifetime. This is computed based on the formula below:

$$CRF = [1/b * (1 + r)^b] * [1 - 1/(1+r)^b] / [1-1/(1+r)^n]$$ where:

r is the discount rate (%)
n is the project's lifetime (no. of years)
b is the construction period (no. of years)

Use of the simplified formula limits application of the model to relatively simple 'build then operate' projects, with linear costs/income for a specified period. Such an approach means that the model cannot explicitly cover complexities such as retrofit projects, non-linear operational scenarios, differences between CfD period and economic plant life etc.

3.2.2.2 Inputs

The levelised cost of a CCS project is a function of a number of input variables, thus results are highly sensitive to these assumptions. Below, we discuss key inputs: costs, performance and temporal items, and discount rate. In our analysis, we assume that all items are project-specific except for the discount rate.

Cost items

Most of the inputs into the formula, in particular the initial capital and O&M costs, depend on the physical design and operation of the project. These assumptions have been provided by ETI and sense-checked by Pöyry[4] against existing literature, for instance, the work conducted as part of the CCS Cost Reduction Task Force.

Other inputs – such as fuel and carbon costs – are highly dependent on factors external to the project and exposed to (potentially large) fluctuations. For the purpose of this calculation, we will use a proxy based on existing long-term price projections (e.g. 15-year average of central case). Other revenue streams apart from electricity sales (in the case of this model, EOR revenues) are dealt with as negative annual opex costs. This reflects the annual revenue one would expect considering defined input parameters.

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4 The assumptions have been checked for all three projects and look consistent across the different projects as well as in the range of the CRTF inputs and Pöyry's internal cost estimates for commercial scale projects. However, the costs for Project B and Project C in particular are towards the bottom end of the range considered by the CRTF (in particular ETI capital costs are lower than the CRTF capital costs for early 2020 projects). The implications for this on the LCOE levels are discussed in Chapter 5.

Performance and temporal items

In the performance group, we include efficiency of the overall CCS project and the capacity factor. The latter is a combination of the availability of the plant (based on both planned and unplanned outages) and the dispatched volumes over a 12-month period expressed in terms of percentage of hours the plant is generation at its full load, when available.

Temporal items are the economic lifetime of the project (*n* in the formula above) and the construction period (*b* in the formula above).

Discount rate

Another key assumption in deriving the levelised cost of a project is the rate of return required by investors (often referred to as the 'discount rate'). Many models assume a flat discount rate across all technologies or at most a technology specific rate whereby the rate varies by technology (but not across projects).

The key aim of the Stage 1.b modelling work will be the incorporation of a risk adjusted discount rate which will show the differences between projects of a particular technology type. This process is discussed in more detail in 3.3 below.

3.2.3 Levelised cost of electricity and CfD strike price

It is important to note that the levelised cost of electricity is not the same as the CfD strike required by a project even after adjusting for the risk premium. LCOEs should be considered as a proxy for the Contract-for-Difference strike price and treated as one of the pieces of information that may feed into the definition of strike prices. Firstly it must be noted that the underlying cost, performance and risk data used as necessary inputs into the process is itself uncertain – this is not an issue specific to this analysis, rather it is inherent in any forward looking projection of prices, but it should nevertheless be recognised.

In addition to the underlying uncertainty in the projections, we would highlight the following key differences between an LCOE approach and a full project specific approach, as may be taken by a project developer[5], to derive the strike prices bids into a CfD auction:

- the duration of CfD support offered may not be the same as the project operating life assumed in the levelised cost calculation. A full approach may encompass a consideration of post-CfD cashflows in the strike price calculation.
- an LCOE calculation represents a simplified approach to the timing of revenue and cost cashflows which would be better represented in a more detailed financial model;
- the discount rates used are pre-tax real and a project will, at least theoretically, be developed against a required post-tax nominal rate of return – there is therefore an implicit effective tax (and inflation) rate assumption in the LCOE calculation which will in practice vary over time and with the specific circumstances of the project developer.
- The discount rate used in an LCOE model should reflect the weighted average cost of capital (WACC) for a project developer and is equal to the weighted return required by potential creditors and equity investors. This will, in practice, vary over time with

5 We have included some of these developer specific factors as qualitative factors in the model but they are not fully represented in the LCOE model.

the market wide Risk Free Rate of Return but will also depend on the project developer as different projects will take different approaches to financing.

- Finally, although we can estimate the costs of a project and therefore the minimum level at which a bidder may enter the market, any auction process may involve the bidder taking into account expectations on competing bidder behaviour.

Where suitable we have included some of these developer specific risk factors as qualitative factors in the model but they are not fully represented in the LCOE model.

3.3 Incorporating risk into the LCOE

Risk is an important metric used by investors to identify potential investment opportunities. There is significant theoretical discussion devoted to the relationship between investment risk and required investment rate of returns. However, the vast majority of the literature focuses on the difference between relatively low risk asset classes such as gilts, bonds and diverse equity markets. The relationship between expected return on an equity investment (or the cost of equity) and the market risk embedded in that investment is well established from empirical evidence. The standard Capital Asset Pricing Model (CAPM) approach relates this return to a risk-free rate plus an additional risk premium. The risk premium is a measure of the additional return that would be demanded by an investor for shifting their money from a riskless investment to a market portfolio of investments.

Looking at choices between project specific investments, we expect to see, on average, a similar approach. In a competitive market it is assumed that when comparing a 'like-for-like' high and low risk project (i.e. identical expected (or P50) parameters but with one project having a smaller spread of possible returns (i.e. through more favourable downside (or P90) parameters) an investor will always choose the project that presents the lowest level of risk, thus maximising the probability of yielding expected returns. In reality for investment to be incentivised for a higher risk project, that project would need to offer more favourable returns on capital investment.

A standard LCOE model uses a flat investor rate of return (RoR) to help determine the viability of a project. Therefore to fully incorporate risk into the LCOE model it is important to have a dynamic RoR dependant on risk. Here, we have used an iterative process to help achieve this by first quantifying risk as a volatility of returns subsequently using this to calculate a risk-adjusted RoR. This methodology is outlined in the four step process defined below::

1. calculate the P50 LCOE and the P90 LCOE for each project based on a constant risk free rate of return (or in practice a low-risk energy project rate of return). The P90[6] LCOE considers the possible time/cost overruns for a given project including potential additional operational costs;
2. use the ratio of the P90 LCOE to the P50 LCOE to create a metric of risk for the project. In general, and other things being equal, we would expect that projects with a higher risk rating will have a P90 LCOE that is further away from the P50 LCOE than projects with a lower risk rating;

6 P90 is defined as a confidence interval encompassing defined projects parameters. In practice these parameters may have no palpable way to quantify them and so the approach that we have adopted is outlined in Annex A .

3. use relationship between the P50 and P90 cases to calculate a risk premium based on a proxy risk-premium curve (derived from data on estimated real discount rates for various assets) – see 3.3.1 below; and
4. increase the risk-free discount rate by this risk premium to calculate a risk-adjusted LCOE.

To be clear, the final LCOE calculations are then based on the P50 numbers, with a risk-adjusted discount factor.

3.3.1 Calculation of the risk premium

In absence of evidence from real CCS projects, a process of qualitative judgment has been necessary to derive the risk premium drawing from literature and other asset types and technologies, such as corporate bond and pre-existing financial models, to derive data points. These data points and judgements have then been combined to build proxy risk-premium curves.

Methodology

For each type of asset we have assessed public sources of data on the estimated real discount rate for the asset and then categorised those asset/investment types into the following categories relating to the volatility of the investment returns:

- Zero – volatility of returns are equal to the overall risk of the market (where the market in this case could be for example long-run energy company bonds)
- Very Low[7] - P90 expectations of returns are very close to P50 but some minor asset investment risk exists over and above a zero or 'risk-free' rate - a typical example would be fluctuations in returns on regulated assets due to imperfect foresight within a given year/price control period.
- Low – Typical investment risk for a mature energy generation technology with a long-track record and little current technology development. A typical example would be a CCGT investment under a tolling agreement with low capex overrun risk but some remaining market risk.
- Medium – Typical investment risk for a technology with some limited commercial track record but where significant technological change is still occurring. Risk of capital and operational difficulties is material in addition to the market risks associated with a Low category risk investment.
- High – Emerging technology with little or no commercial track record and rapid technological change creating a wide range in cost and NPV estimates. In this range, technical performance becomes a uncertainty in addition to the Medium category risks.
- Very High – Energy sector investment where there is a large risk to the overall capital. This would include very early stage potential breakthrough technologies but also activities such as oil & gas exploration.

Whilst the volatility of returns at the Low end of the spectrum is observable in the market, the risk premium for progressively riskier asset classes is more difficult to assess. In extreme cases we have observed early stage projects where a 'downside' (i.e. decidedly

7 Note that the 'High/Medium/Low' categories here refer to general energy projects and should not be confused with the ratings defined for the potential CCS projects.

pessimistic) P90 LCOE estimate could vary by as much as 100% from the P50 – e.g. a deep geothermal project where the volume of energy recovered could be much lower than expected or an oil company expecting to drill two wells to recover a given oil volume but actually needing to drill four. *N.B. In these examples LCOE is not the measure of project success/viability. The examples serve to demonstrate how double the expected expenditure could be required to yield the expected resources (oil, electricity etc.).*

The Zero and Very Low risk categories have very low risks and very low returns and do not share much in common with more risky asset specific investments. After consideration these categories have been excluded from the curves we have developed as they disrupted the shape of the curves at the bottom end of the market. For each of the remaining categories we have estimated a volatility factor range as shown in Table 2 (where the volatility of returns is expressed as the % overrun of P90 levelised costs compared to P50 case). The Central Risk Premium Curve has been estimated based on internal Pöyry data and assumptions taken in Q3 2014 on the asset types described above. As an example Pöyry hold a continuously updated set of internal estimates of offshore wind costs which we use as a key driver of investment decisions in our quarterly market model update process. This data set includes Central cost expectations as well as a range from Very Low to Very High reflecting current uncertainties over future costs. We have then used the range between a Central cost assumption and Very High cost assumption for a new wind project as a proxy for the P90 overrun potential for offshore wind (in this case ~40%). As offshore wind is a typical ‘Medium’ risk project type we utilise this as a Central Risk Premium data point for Medium Risk asset types.

However, we must realistically recognise that, in part due to the lack of existing literature and work on this issue, there is significant uncertainty in the Risk Premium Curves. We have reflected this uncertainty by creating a Low and High Risk Premium Curve which are +/-30% around the Central[8]. The +/-30% has been selected as a pragmatic approach which captures the range of recent specific investment analysis conducted by Pöyry (in particular on GB based CCGTs and Round 2 offshore windfarms).

Table 2 – Volatility of returns of different energy asset types

% P90 Overrun on P50		Risk premium Curve High	Central	Low
Asset Type	Low	11%	15%	20%
	Medium	28%	40%	52%
	High	42%	60%	78%
	Very High	70%	100%	130%

For each risk category we have then developed a list of relevant energy technologies using Oxera’s survey of overall risk perception for energy generation technologies as

8 The ‘High’ Risk Premium curve has 30% lower volatilities than the Central and the ‘Low’ scenario has 30% higher volatilities. In effect we are saying that the a Low risk asset type will have a risk premium of between 11% and 20% - lower P90/P50 numbers in our curves mean that risk is translated more sharply into higher discount rates as shown below.

defined in the 2011 report for the CCC[9] and shown in Table 3 below. For each technology type we have then taken the average discount rate based on the Oxera analysis. This analysis suggests a range of discount rates for Low to High Risk projects of 7.5% for CCGT and Hydro to 14.5% for Tidal Barrage and CCS. These discount rates are also in line with the DECC 2013 Electricity Generation Costs publication[10].

Table 3 – Overall Risk Perception and resulting discount rates for a range of Energy Generation Technologies

Low		Medium		High	
CCGT	7.5%	Biomass	11%	Tidal stream	14.5%
Hydro ROR	7.5%	Nuclear	11%	Tidal barrage	14.5%
Solar PV	7.5%	Offshore wind	12%	CCS, coal	14.5%
Dedicated biogas (AD)	8.5%	Wave (fixed)	12%	CCS, gas	14.5%
Onshore Wind	8.5%			Wave (floating)	15.5%

Source: Oxera: Discount rates for low-carbon generation and renewable generation technologies for the CCC, 2011

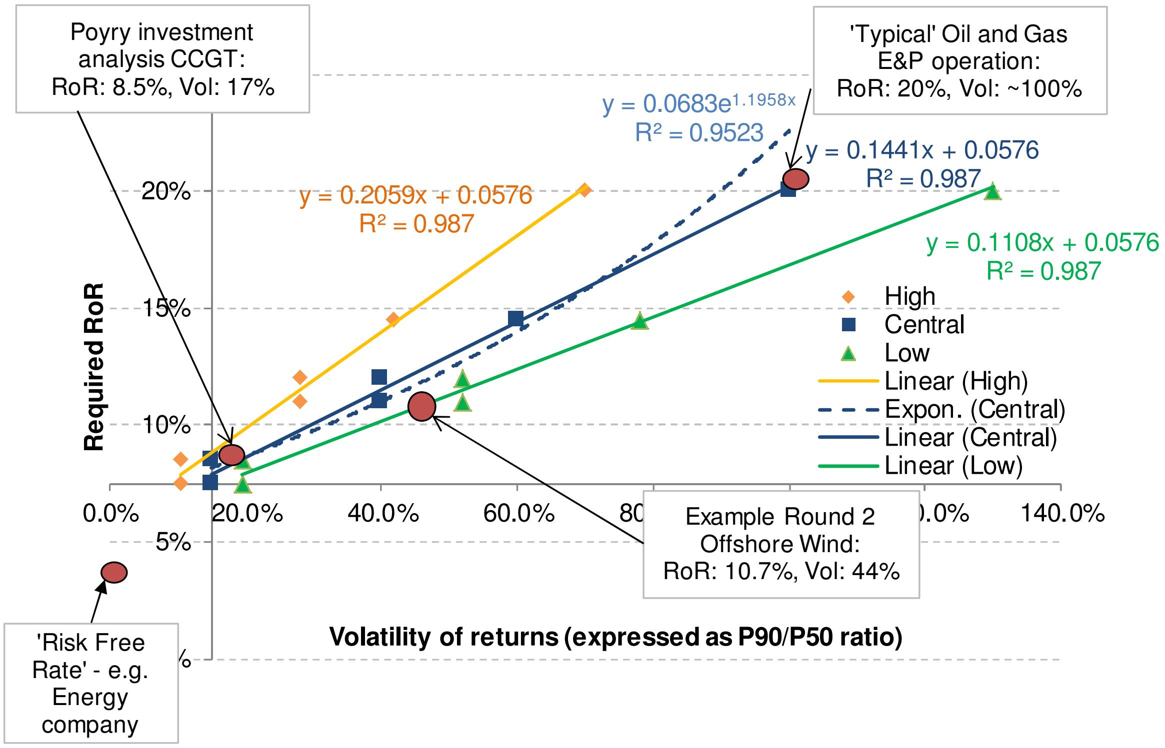
By mapping the mean discount rates for the asset type groups against the return volatility estimates shown in Table 1 we have created a series of data points for High, Central and Low Risk Premiums (the orange, blue and green points in Figure 3).

By estimating a linear relationship between discount rate and volatility of returns, we have created High, Central and Low Risk Premium Curves are as shown in Figure 3. We have also calculated an alternative Central 'Exponential' curve (regressed utilising the exponential function resulting in a smooth, curved relationship as opposed to a linear relationship) which can be selected in the model to test the sensitivity of conclusions to alternative trend lines. Finally, we have also compared and adjusted the premium curves to ensure that it is in line with recent project investment analysis conducted by Pöyry on CCGT and Round 2 offshore windfarms.

9 This was derived from a combination of available literature combined with estimates recorded by industry participants; http://www.oxera.com/Oxera/media/Oxera/downloads/reports/Oxera-report-on-low-carbon-discount-rates.pdf?ext=.pdf

10 'Electricity Generation Costs', DECC, July 2013. Although there are some differences in e.g. Nuclear and Wave technology hurdle rate assumptions, this may be partly explained by the assumption of a lower risk perception under the CfD regime, through the removal (or at least significant reduction) in most of the electricity market risk (and fuel risk).

Figure 3 – Risk premium vs. Return Volatility curve for the GB power sector



Due to the uncertainty around the curves we have transferred all four curves to the model and allowed the user to define which of these is used in the analysis. The curve coefficients themselves are also adjustable in the model if required.

3.4 Model risk categorisation

In this section, we outline the three main elements used to categorise risk in the Risk Adjusted LCOE model – these elements remain broadly unchanged from the Stage 1.a Risk Weightings Model.

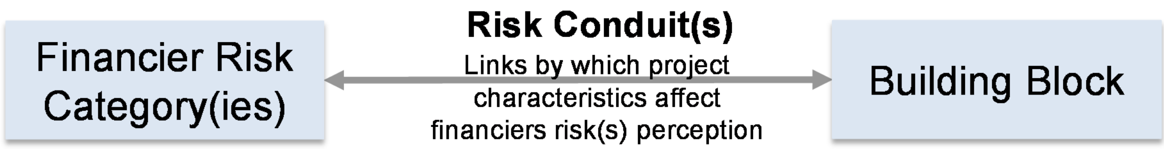
These model elements have been developed to represent both the major risks that are important to a financier of a major infrastructure project, and the features of a CCS project that may influence a financier's perception of said risks.

The three defining elements are:

- the Financier Risk Categories – these are various risks that a financier would consider when making an investment decision;
- the Building Blocks (and their Sub-categories) – these are characteristics of a project, which define and differentiate a project in terms of its investment riskiness; and
- the Risk conduits – these are the link by which a project characteristics would influence the financier's perception of risk.

A representation of the relationship between these three elements is shown below in Figure 4

Figure 4 – Relationship between LCOE model elements



3.4.1 Financier Risk Categories

These are different types of risk that a financier considers when deciding to make an investment as the potentially impact expected project returns and/or ability to repay debt in a timely manner. These often correspond to particular cost or revenues uncertainties (e.g. construction risk through capex overruns/contingency or through project delays), or other intangible aspects (e.g. credit risk, etc.) that require various mitigation measures.

Pöyry have determined there to be the following categories which capture the spectrum of possible risks:

- Construction Risk;
- Technology Risk;
- Operational Risk;
- Ownership & Contractual Risk;
- Policy & Regulatory Risk; and
- Permitting & Consent Risk.

Further details on each of these categories will now follow, together with an assessment of their corresponding conduits. Further details on conduits may be found in Section 3.4.3

Construction Risk

This risk includes all occurrences that may affect the project during construction. For the purpose of our Risk Weightings Model, we define Construction Risk as the risk of incurring higher capital expenditure than the original plan and the risk of completing the project later than expected (hence impacting returns by delaying first revenues) – Conduit 1 is Capex overruns & Conduit 2 is Delays to project completion

Technology Risk

This is linked to external and internal factors that cause the technology-system to stop or slow down compared to prediction, influencing the economics of the project (e.g. design flaws, or inexperience with technology). In our Risk Weightings Model, we consider that this risk materialises in a potentially lower than expected Availability (Conduit 3) of any of the components (e.g. storage injectivity). Technology risk also materialises in the form of a lower than expected project efficiency. In the model, this feeds into the calculation of the fuel O&M costs.

Operational (Market) Risk

This arises both from personnel and equipment failures and related to all situations reducing the performance of the project. It may feed into the project economics through cancellation and standby costs, testing and commissioning, operation and maintenance, servicing contracts, insurance, and/or staffing. In this category, we also include risks related to market conditions, such as fluctuations in the cost of fuel, carbon and electricity prices as well as implications on plant dispatch patterns. In our model, it materialises as Opex overruns (Conduit 4).

Ownership & Contractual Risk

This category represents a wide range of risks, spanning from counterparty risk (e.g. contractor / design engineer experience, power offtaker's solvency) to complexity of contractual relationships between all project stakeholders, legal framework, ownership, responsibility, supply agreements, etc. These risks can materialise during the construction period as well as the operational lifetime of the project.

Most of these risks are of an intangible nature, i.e. not directly linked to a physical characteristic of the CCS project. Financiers would typically identify these risks, consider whether they are an obstacle for further investment considerations and assess whether measures could be implemented to mitigate their potential impact. Overall, this would impact the cost of financing and the conditions at which funds would be provided to the project sponsor (i.e. Financing terms, or Conduit 5).

Policy & Regulatory Risk

This relates to the regulatory framework and any external political interference that may affect the project both during development and operations. Examples are a change in regulation with respect to long-term liabilities of CO_2 leakage, stability of subsidy scheme, public support, etc. Similarly to the Ownership & Contractual Risk above, most of the risks in this group are not related to a physical characteristic of the project, and would impact the cost of financing and the conditions at which funds would be provided to the project sponsor (i.e. Financing terms, or Conduit 5).

Permitting & Consent Risk

This is a typical binary risk and relates to the ability of the developer/sponsor to obtain all the permits and consents required for the project to be constructed, commissioned and operated during its lifecycle. We have not included this category of risk in our '@FID' model, as we assume that financiers will only consider investing once all these authorisation processes have succeeded.

3.4.2 Building Blocks

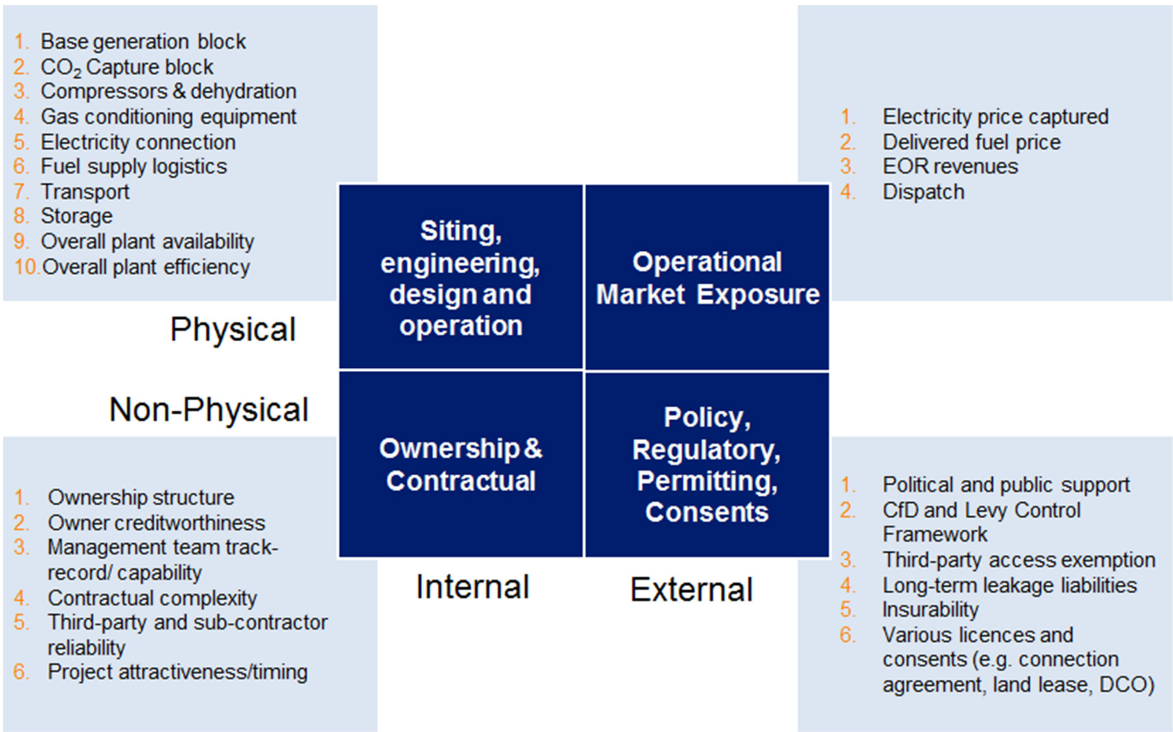
These are characteristics of a project which define and differentiate a project in terms of its riskiness as an investment proposition. These may well be physical but could also be contractual or capability related (e.g. capture technology or storage choice). Our aim is to identify the minimum number of building blocks required to define a project's risk to keep the message clear. We have therefore tended to take broad definition of a block rather than break them down into component parts, and have split them into four broad areas:

- **Siting, engineering, design and operation** – Physical elements of the project chosen site, engineering, design and operation which typically must be decided by completion of the FEED process.
- **Operational Market Exposure** – Elements of the project related to exposure to external factors, which may vary over the project lifetime, such as the cost of fuel or the running pattern of the project.
- **Ownership & contractual** – Generally non-physical but internal attributes of the project related to the develop capacity, management and contractual considerations.

- **Policy & Regulatory** and **Permitting & Consents** – Generally non-physical but external attributes of the project related to local and national government and body decisions.

These four macro-areas can be split further into a series of sub-categories, which we have detailed in Figure 5. Annex B contains further details on these sub-categories.

Figure 5 – Building Block Sub-categories



3.4.3 Risk Conduits

These are the route(s) by which a particular Building Block will influence costs and thereby a Financier Risk Category (e.g. choice for Capture Technology Building Block will influence the likelihood and scale of capital cost overruns). One Building Block may have multiple conduits – i.e. many ways in which it influences the expected returns/debt repayment ability of the project. For example, Capture Technology choices will also influence the risk of opex overruns and lower plant availability.

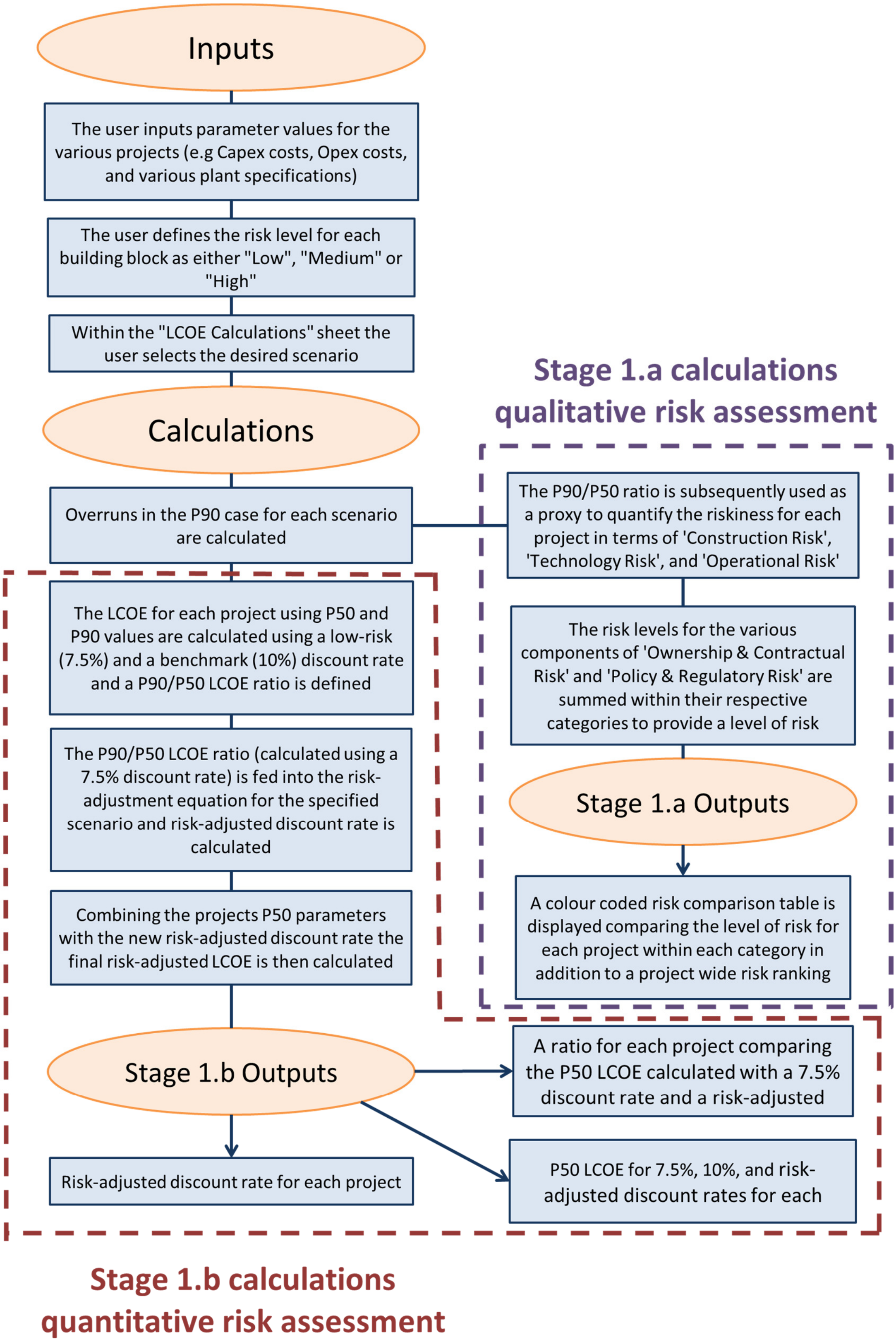
In our model, we have considered the following conduits:

- Capex overruns – related to Construction Risk;
- Delays in project commissioning – related to Construction Risk;
- Availability – related to Technology Risk;
- Opex overruns – related to (Market) Operational and Technology Risk; and
- Financing terms – related to Ownership & Contractual and Policy & Regulatory Risks.

3.5 How to use the model

In this section, we outline the function of the Risk Weighted LCOE Model, the key inputs required and describe the key outputs. The model itself is currently based in Microsoft Excel, and has been expanded from the Stage 1.a Risk Weighting Model. We have subdivided the process into three stages: the user input, calculation and output stages. Figure 6 displays a flow chart outlining these three stages and they are described in turn in the sections below.

Figure 6 – Model flow chart



User input stage

For each of the three short-listed projects – Project A, B and C – the user will input into the Input Sheet a number of **assumptions quantifying the physical characteristics of the project**, or Building Blocks Sub-categories. These assumptions are representative of the user's best estimate, hereafter referred to as P50 expectations.

The user will input general project information, i.e. the expected net export capacity to the grid, the generation fuel (i.e. coal or gas), the expected availability of the plant based on planned outage time, the overall efficiency, the expected number of months from FID to completion[11], the project lifetime and the rate of effectiveness in capturing the CO2 produced from the combustion.

The following Building Block Sub-categories requires capex (GBP million) and non-fuel opex (GBP million per annum) cost inputs:

- Base generation block;
- CO2 capture block;
- Compressors & dehydration block;
- Other (inc. Gas conditioning equipment);
- Electricity connection;
- Fuel supply logistics[12];
- Transport; and
- Storage.

For each of the blocks above, the user will also need to include an estimate of the level of availability based exclusively on expected unplanned down-time. The overall project availability will then be calculated as the product of project's planned and single element's unplanned outages[13].

Four more Building Blocks Sub-categories (all falling into the Operational Market Exposure macro-category) – i.e. electricity price captured, delivered fuel price, EOR revenues and dispatch all require assumptions, which are expressed as a percentage of the underlying running pattern (for dispatch) or electricity/fuel/revenue price scenario (all other categories) expected to be realised by the project.

The Model then applies these percentage assumptions to single values, which are a proxy for the central view of EOR revenues, wholesale electricity, fuel and carbon prices averaged over the 2022-2035 period. We acknowledge there is a high degree of uncertainty around these prices/costs, however, for the purpose of this analysis, we have

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11 For simplicity, completion is assumed to be reached once the plant is fully commissioned.

12 Operational expenses for this block are assumed to be not material, therefore not required.

13 This approach assumes that unplanned outages are the product of outages on capture, transport and storage thereby assuming that outages take place when all other elements are fully functioning: compounding the effect on the overall project availability. For individual elements at the capture site we assume that the overall unplanned outage level is equal to the availability of the least reliable component (i.e. we assume that breakages occur simultaneously). Although this approach is somewhat simplistic, we opted to use it the final model as it gives a reasonable level of both P50 and P90 levels of availability.

adopted a simplified approach. Proxies for these values are hardcoded in the tab labelled 'Legend', and can be amended, as appropriate.

Finally, the user will need to enter a **qualitative risk assessment of each Sub-category** by selecting the appropriate scoring from the drop-down menu – High, Medium or Low. This scoring exercise is to be performed for all the Sub-categories falling under the Construction, Technology, Operational, Ownership & Contractual, and Policy & Regulatory Risk. As discussed earlier in this report, those falling under the Consents & Permit Risk are assumed to be resolved @FID. A description of each of the main sub-categories that feed into the LCOE calculation is provided in the Glossary sheet alongside a key attributes for Low, Medium and High Risk category selections. This is also provided in Annex B.

During the course of the two workshops we have identified a number of characteristics qualifying a project as a Lower Risk versus a Higher Risk Project and interpolated these results to quantify a Medium Risk project. Within the model guidance is provided for each subcategory facilitating ease-of-use for the model. This helps the user identify what is encompassed in each defined risk category.

Please note that the user is given the choice of providing an 'Overall' assessment for each Building Block Sub-category, or scoring the risk of each Sub-category by conduit (i.e. Capex overruns, Delays, Performance and Opex overruns). By selecting 'NO' in the drop-down menu located at the top-left of the Input Sheet, the model will run based on an Overall scoring, whereas selecting 'YES', it would run on a by-conduit basis (e.g. the base generation block may be riskier from a capex overrun perspective than from an availability or opex overrun one).

Calculation stage

Calculations required to produce the risk-based ranking of projects Risk Allocation of Shortlisted Projects (Stage 1.a) are performed in the Risk-weighting Calculations sheet, whereas those related to the computation of the LCOE results Risk Adjusted Energy Cost Model (Stage 1.b) are included in the LCOE Calculations tab.

Risk-weighting Calculations

The P50 input assumptions and the risk choice for the Building Block Sub-categories are used by the model to calculate the corresponding P90 expectations. Each scoring level (High, Medium or Low) translates, for instance, into a percentage adjustment that is applied to the P50 input to produce the P90 figure. For instance, should the base generation block be considered High risk, the P50 input is uprated by a factor of 1.45 (i.e. P90 is 45% higher than the P50 – mid-point of the questionnaire range 'd.30-60%'[14]), whereas if it is Low risk, the factor is 1.10 (i.e. P90 is 10% higher than the P50 – mid-point of the questionnaire range 'd.5-15%').

For each Conduit, a risk metric is computed so as to allow weighting each Building Block Sub-category by its relative 'importance' in the overall cluster. Different Conduits and

14 During the second workshop, the wider ETI team has produced an assessment of what these adjustment factors should be. Participants have selected for each Sub-category and Conduit a range of, for instance, percentage capex overruns. Results of this survey process are presented in Annex A and have been incorporated into the Risk Weighting Model by importing the selected ranges in the Calculation sheet under each of the High / Low Risk column headings. The Medium ranges have been identified as the mean value of all votes cast (for both high and low risk projects). Ranges are provided in the Legend sheet.

Financier Risk Categories will have different numerical approach to the computation of the risk metric and the weighting.

For example, the risk metric for the Capex overruns conduit is produced by dividing the total P90 (in GBP million) by the total P50 corresponding figure (and subtracting one). This results into a factor between zero and one[15]. The approach takes into consideration the relative importance of each sub-category's contribution to the total capex as well as the underlying 'uncertainty' in that value (P50 to P90 uncertainty). A higher overall capex contribution and a greater uncertainty will mean a higher weight, hence a higher risk for that item. A similar approach is used for other conduits, such as the Delays, Performance and Opex[16].

In detail, for Delays, the P90 value is calculated as the maximum delay that can be accrued based on individual sub-categories. The risk metric is then equal to the P90 value divided by the P50 minus one.

For Performance, the P90 value is calculated by subtracting from the assumed overall planned availability of the CCS project the product of the unplanned availability factors of each sub-category. This results in the total P90 availability (accounting for both the planned and unplanned outages). The metric is then calculated as P90 divided by P50 minus one.

For Opex, all non-market related operational costs are treated as explained for the capex above. The Sub-categories related to the Operational Market Exposure have been monetised into a GBP million per annum value, which is then accrued to the overall opex P50 and P90. The risk metric is then the usual factor calculated as the ratio between the overall P90 and P50 minus one.

Given the intangible nature of sub-categories falling under the Ownership & Contractual and Policy & Regulatory Risks, we have approached these differently. High, Medium and Low riskiness levels have been translated into a score of three, two and one, respectively, and summed up across Financier Risk Category: the higher the total score, the higher the risk. Please note that this is a simplified approach, which does not account for the relevance of each category, or its economic impact.

LCOE Calculations

The LCOE calculations feed inputs through from the Risk Weighted Calculations spreadsheet and applies the formulae as described above. It is worth noting that from this sheet the scenario used to calculate the risk-adjusted discount rate can be selected. Selecting a scenario will calibrate the equation used to calculate the risk-adjusted discount rate from a choice of 'Low', 'Central' 'Central Exponential', or 'High' scenarios. The risk-adjusted discount rate is calculating using the P90/P50 LCOE ratio calculated at a flat 7.5% (low-risk) discount rate. From this it is possible to determine a risk-adjusted discount rate using the methodology described in section 3.3.

This page also contains a breakdown of each of the three components for the risk-adjusted LCOE (Capex, Fixed Opex, variable Opex). The final calculation that we have

15 For the purpose of this exercise, we have assumed that costs under the P90 scenario cannot be more than the double of those expected under the P50 scenario. The Model can however accommodate a different approach, if needed at a later stage.

16 This process required a number of high-level assumptions, for instance the level of wholesale or fuel price.

added to this page is an LCOE calculated with a flat discount rate of 10%. This has been added to the model simply as a benchmark for comparison between different projects, at a commonly used benchmark for other technologies.

Output stage

Both the Risk Weighting Model and the LCOE model summarise their respective results in the Output sheet. These results are extracted from the calculation sheets. The outputs for the Risk Weighting Model are compiled into a weighted-risk score. In the case of 'Construction', 'Technology', and 'Operational' risks this is calculated as a ratio between P90 and P50 costs (as we have assumed that the overrun in the P90 scenario cannot be more than double the P50 this yields a score out of 100). As a consequence of using the P90/P50 ratio, components with more risk (i.e. large potential for Capex overruns) carry more weight in the ranking process. For the 'Ownership & Contractual Risk' and 'Policy & Regulatory Risk' it is defined by an absolute comparison of individual risk parameters. The rank for each Financier Risk Category is then fed into a colour coded project ranking matrix and the projects given an overall risk ranking defined by the sum of individual components.

The results of the LCOE output are summarised in a table which compares LCOE values calculated with a 7.5%, 10%, and a 'Risk-Weighted' discount rate applied. This allows for easy comparison of project viability with relation to risk.

Protection of cells/sheets

In the final model version, appropriate protection of calculation, outputs and any other 'fixed' cells will be provided (with password communicated to the ETI) to avoid inadvertent or undesirable modifications to the operation of the Model.

4. RISK ALLOCATION OF SHORTLISTED PROJECTS (STAGE 1.A)

This chapter outlines the three short-listed risk archetypes, details the inputs used within our model and provides a summary of the results obtained from this exercise.

4.1 Project archetypes

For the purposes of this stage of the project, we have selected three development projects in order to span a range of key risk attributes. Further details of these attributes are given in Section 3.4. Below we describe the main characteristics by Building Block and the risk scoring allocated to each Sub-category for each project archetype in turn assuming FID takes place in 2022. Project specific model input assumptions are provided in Annex C.

4.1.1 Overall Low Risk archetype[17]: Project A – Aire Valley

Siting, Engineering, Design & Operation

This project would involve a 'state of the art' coal 'base' generation technology paired with a capture approach which has good operating experience at a pilot/demo scale. There are also other developing projects currently proposing to use the same technology which are more advanced than this project, which will have operational experience by 2022 (so it would not be the first of its kind). As we have assumed that we are in 2022, White Rose would have already been in operation for around 2 years, and as a geographically proximate project should aid in knowledge transfer and risk reduction. Therefore, this building block would have a low risk ranking. Compression, dehydration and gas conditioning would all be using commercially sized products with sufficient redundancy built in to ensure specifications can be met and high levels of availability.

The proposed power station site is well located (<500m) from existing unutilised and sufficiently scaled electricity connection as well as an existing fuel supply/connection point, and it would flow into a planned onshore pipeline built as part of the Commercialisation Programme with large spare capacity of multiple times required flow. An available potential feed-in point is located within 5 miles of the proposed site, which would entail some onshore works. Despite this, however, the risk ranking of this building block remains low.

The site will use the planned storage site developed as part of the Commercialisation Programme (5/42) with anticipated large volumes of spare capacity. By 2022 it will have been operational for 2 years. Already, the secondary store has been identified with a high degree of certainty, with no EOR planned.

Operational Market Exposure

The fuel purchase strategy exposes the project to a low risk from price fluctuations (for example, long-run indexed prices[18]), with an established route-to-market for power with no imbalance exposure and no EOR risk.

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17 i.e. Low risk for a CCS project

18 Long term fuel supply agreements for both coal and gas under bilateral agreements should be available in the market for a good proportion of the lifetime of a CfD contract. Indeed a CCS project may choose to take multiple parallel contracts for certain volume percentages to mitigate counter party risks. Although the pricing terms of such contracts are not readily

Ownerships & Contractual

The current ownership and contractual structure minimises reliance on third parties with a low-complexity 'standard' contract structure. All the major contracts for construction and operation are also already in place with reliable counterparties and a non-performance warranty. Moreover, it is headed by an experienced project development team (who have already developed the White Rose project).

Policy & Regulatory and Permitting & Consents

Given the similarity to existing projects and the lack of new onshore works, public support for CCS more generally and specific support is likely. Policy support through the CfD offer is secured with a 'sufficiently' attractive strike price and clear terms and conditions. All elements of the plant are consented and permitted within well-defined and understood rules and limits. CCS liability limits are also clear for all chain elements, such that appropriate insurance is available on reasonable terms.   With storage leakage liability having the potential to be insured before handing over to government at a pre-defined point, the risks for these building blocks are low.

Risk scoring

All sub-categories score Low risk.

4.1.2 Overall Medium Risk archetype: Project B – Humber estuary

Siting, Engineering, Design and Operation

This is a state of the art gas 'base' generation technology paired with a reasonably novel capture approach (e.g. advanced amine) previously operated at a pilot/demo scale only. The capture elements are relatively new and would involve a significant (but relatively low risk) scale increase, which would lead to a medium risk ranking. Together with compression, dehydration and gas conditioning using new 'above-commercial' sized products and the push for a lean solution means low in-built redundancy and/or tight specification margins, these two building blocks would lead to a high risk ranking.

As with Project A and White Rose, this power station site is well located (<500m) for an existing under-utilised and sufficiently scaled electricity connection as well as an existing fuel supply/connection point, will flow into a planned onshore pipeline built as part of the Commercialisation Programme with large spare capacity, sufficient for multiples of the required flow. However the nearest available potential feed-in point is around 40km from the site, entailing some major onshore works, which raises the risk profile. The site will use the planned storage site developed as part of the Commercialisation Programme (5/42) with anticipated large volumes of spare capacity. Already, the secondary store has been identified with a high degree of certainty, with no EOR planned

Operational Market Exposure

As with Project A, the fuel purchase strategy is aimed at lowering the risk from price fluctuations (for example, long-run indexed prices) but as the fuel used is gas it is

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observable, anecdotal evidence suggests from historic financing arrangements suggests that fixed pricing structures or partially indexed pricing structures are possible. Obviously such a pricing arrangement is a transfer of risk to the other party and as such it would come at a cost.

assumed there is some remaining market exposure. The project has an established route-to-market for power with no imbalance exposure and no EOR risk.

Ownerships & Contractual

The current ownership and contractual structure minimises reliance on third parties with a low-complexity 'standard' contract structure. All the major contracts for construction and operation are also already in place with reliable counterparties and a non-performance warranty. Unlike Project A, it is led by a semi-experienced project development team, with no current UK projects developed, which raises its risk profile.

Policy & Regulatory and Permitting & Consents

There is general public support for CCS, although in the case of this project, specific support is uncertain, due to the need for major onshore works, leading us to rank this profile as a medium risk. Policy support through the CfD offer is secured with a 'sufficiently' attractive strike price and clear terms and conditions. All elements of the plant are consented and permitted within well-defined and understood rules and limits. CCS liability limits are also clear for all chain elements, such that appropriate insurance is available on reasonable terms. With storage leakage liability having the potential to be insured before handing over to government at a pre-defined point, the risks for these building blocks are low.

Risk scoring

Scoring has been assumed as follows:

- **Medium risk** – Base generation, CO_2 capture, compressors and dehydration blocks, gas conditioning equipment and plant efficiency, transport, storage, fuel price risk, management track record, (political) and public support.
- **Low risk** – All other sub-categories.

4.1.3 Overall High Risk archetype: Project C – North-east England

Siting, Engineering, Design and Operation

This is a reasonably novel coal 'base' generation technology (IGCC) paired with a capture approach previously operated at a pilot/demo scale only. The capture elements are relatively new and would involve a significant scale increase, which would lead to a high risk ranking. Together with compression, dehydration and gas conditioning using new 'above-commercial' sized products and the push for a lean solution means low in-built redundancy and/or tight specification margins, these two building blocks would lead to a high risk ranking.

Unlike the other two projects, whilst this project will be developed on a brownfield site, a new electricity connection, new fuel supply will be needed to be built as well. In addition, a new dedicated onshore and offshore pipeline route would be required. This raises the potential for overruns significantly when compared to the two previous projects. With regards to storage, a new offshore storage site outside of the Commercialisation Programme, which raises the risk of overrun still further.

Operational Market Exposure

As with Project A, the fuel purchase strategy exposes the project to a low risk from price fluctuations (for example, long-run indexed prices), with an established route-to-market for power with no imbalance exposure. We have assumed the project has some small associated EoR revenues but that they are minor and there is only a low EOR related risk.

Ownerships & Contractual

The current ownership and contractual structure minimises reliance on third parties with a low-complexity ‘standard’ contract structure. All the major contracts for construction and operation are also already in place with reliable counterparties and a non-performance warranty. Unlike Project A, it is led by a semi-experienced project development team, with no current UK projects developed, which raises its risk profile.

Policy & Regulatory and Permitting & Consents

There is general public support for CCS, although in the case of this project, specific support is uncertain, due to the need for major onshore works, leading us to rank this profile as a medium risk. Policy support through the CfD offer is secured with a ‘sufficiently’ attractive strike price and clear terms and conditions. All elements of the plant are consented and permitted within well-defined and understood rules and limits. CCS liability limits are also clear for all chain elements, such that appropriate insurance is available on reasonable terms. With storage leakage liability having the potential to be insured before handing over to government at a pre-defined point, the risks for these building blocks are low.

Risk scoring

Scoring has been assumed as follows:

- **High risk** – All siting, engineering, design and operation sub-categories.
- **Medium risk** – Management track record, (political) and public support.
- **Low risk** – All other sub-categories.

4.2 Input assumptions

In order to complete the scoring exercise at the end of Stage 1.a, generic input assumptions for a CCS project had to be defined, these can be found in Annex C.

For Stage 1.b project specific input assumptions have been provided by ETI and have then been inputted into the model in order to calculate LCOE values. The projects archetypes are as conceptualised for the early 2020’s, after some years of operation of the projects under the commercialisation programme competition. They are in effect ‘early Nth Of A Kind’ (NOAK) costs as we assume that some additional ‘First Of A Kind’ (FOAK) cost/risks will have been removed by previous projects. Work conducted by the UK CCS Cost Reduction Task Force suggests that FOAK project capital costs could be around 1/3 higher than those in the early-NOAK stage. T

he input assumptions are shown in Figure 7, Figure 8, and Figure 9 below. The Capex and Opex values provided are based on Q1 2009 ETI studies, however these figure are based on ‘peak market’ prices and it is assumed that general inflation has been counteracted by relaxation of constraints in the EPC market such that the prices are viewed as applicable on a real 2013 basis. The numbers have been sense checked against Pöyry internal figures as well as against CCS UK Cost Reduction Taskforce expectations and, although the approach and breakdown of costs is somewhat different, the numbers are broadly consistent.

Figure 7 – Input assumptions for Project A – Aire Valley

Project A - Aire Valley

Subcategory>>	Conduits>> Overall	Capex	Delays	Availability / Efficiency	Opex	Financing terms	Input assumptions>> Capex (£m)	Performance (%)	Opex £m p.a.)	
	Chose from drop-down menu									
Base generation block	Low	Low	Low	Low	Low		1,150	97%	55	
CO2 capture block	Low	Low	Low	Low	Low		423	95%	25	
Compressors & dehydration block	Low	Low	Low	Low	Low		149	100%	10	
Other (including gas conditioning equipment)	Low	Low	Low	Low	Low		0	100%	0	
Electricity connection	Low	Low	Low	Low	Low		0	100%	0	
Fuel supply logistics	Low	Low	Low	Low			0	100%		
Transport	Low	Low	Low	Low	Low		60	99%	14	
Storage	Low	Low	Low	Low	Low		200	99%	6	
Overall CCS plant efficiency	Low			Low				34%		
Electricity price captured	Low				Low				98%	% of referenc
Delivered fuel price	Low				Low				100%	% of Central v
EOR revenues	n.a.				n.a.				100%	% of Central v
Dispatch	Low				Low				100%	

Net capacity to grid	626	MW
Fuel	Coal	*Chose from drop-down menu*
Overall planned project availability	90%	
Overall planned & unplanned availability	83%	
Months from FID to project completion	48	months
Project Lifetime	25	Years
Emission Capture Effectiveness	90%	

Figure 8 – Input assumptions for Project B – Humber Estuary

Project B - Humber Estuary

Subcategory>>	Conduits>> Overall	Capex	Delays	Availability / Efficiency	Opex	Financing terms	Input assumptions>> Capex (£m)	Performance (%)	Opex £m p.a.)	
	Chose from drop-down menu									
Base generation block	Medium	Medium	Medium	Medium	Medium		507	97%	33	
CO2 capture block	Medium	Medium	Medium	Medium	Medium		390	95%	8	
Compressors & dehydration block	Medium	Medium	Medium	Medium	Medium		126	100%	4	
Other (including gas conditioning equipment)	Medium	Medium	Medium	Medium	Medium		0	100%	0	
Electricity connection	Low	Low	Low	Low	Low		0	100%	1	
Fuel supply logistics	Low	Low	Low	Low			0	100%		
Transport	Medium	Medium	Medium	Medium	Medium		100	99%	10	
Storage	Medium	Medium	Medium	Medium	Medium		150	99%	4	
Overall CCS plant efficiency	Medium			Medium				51%		
Electricity price captured	Low				Low				98%	% of referenc
Delivered fuel price	Medium				Medium				100%	% of Central v
EOR revenues	n.a.				n.a.				100%	% of Central v
Dispatch	Low				Low				100%	

Net capacity to grid	860	MW
Fuel	Gas	*Chose from drop-down menu*
Overall planned project availability	90%	
Overall planned & unplanned availability	83%	
Months from FID to project completion	48	months
Project Lifetime	25	Years
Emission Capture Effectiveness	90%	

Figure 9 – Input assumptions for Project C – North-east England

Project C - North-east England

Subcategory>>	Conduits>> Overall	Capex	Delays	Availability / Efficiency	Opex	Financing terms	Input assumptions>> Capex (£m)	Performance (%)	Opex (£m p.a.)	
	Chose from drop-down menu									
Base generation block	High	High	High	High	High		688	97%	34	
CO2 capture block	High	High	High	High	High		761	95%	36	
Compressors & dehydration block	High	High	High	High	High		43	100%	3	
Other (including gas conditioning equipment)	High	High	High	High	High		0	100%	0	
Electricity connection	High	High	High	High	High		15	100%	1	
Fuel supply logistics	High	High	High	High			30	100%		
Transport	High	High	High	High	High		270	99%	7	
Storage	High	High	High	High	High		220	99%	6	
Overall CCS plant efficiency	High			High				38%		
Electricity price captured	Low				Low				98%	% of reference price
Delivered fuel price	Low				Low				100%	% of Central view
EOR revenues	Low				Low				100%	% of Central view
Dispatch	Low				Low				100%	

Net capacity to grid	730	MW
Fuel	Coal	*Chose from drop-down menu*
Overall planned project availability	90%	
Overall planned & unplanned availability	83%	
Months from FID to project completion	48	months
Project Lifetime	25	
Emission Capture Effectiveness	90%	

4.3 Risk scoring outcome

As expected, the outcome of the modelling exercise is highly influenced by the set of assumptions and the risk scoring inputs of sub-categories. The Aire Valley project archetype was designed at the outset to be the less risky project, the North-east England to be the riskiest one and the Humber Estuary to rank in the middle.

The Model mapped these assumptions and yielded the colour-coded ranking presented in the table below: green (score 1) is the less risky project, red (score 3) is the riskiest.

Table 4 – Ranking of quantified risk categories

Financier Risk	Conduits	Project A - Aire Valley	Project B - Humber Estuary	Project C - North-east England
Construction Risk	Capex	1	2	3
	Delays	1	2	3
Technology	Availability	1	2	3
Operational Risk	Opex	1	2	3
Ownership & Contractual Risk	Financing Terms	1	2.5	2.5
Policy & Regulatory Risk		1	2.5	2.5

Obviously, once 'real' projects are considered (and appropriate project-specific assumptions included), the Model will operate at its intended capacity and produce a non-pre-designed result. Currently in the LCOE model it assumed that all permits and consent are obtained prior and separately to project FID. There is no simple way of translating these risks into the LCOE calculation. Therefore, these risk categories, and the other elements contained in the Ownership & Contractual Risk and Policy & regulatory Risk categories do not feed in to the LCOE model.

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5. KEY RISK WEIGHTED LCOE MODEL RESULTS (STAGE 1.B)

This chapter presents the key findings from the Risk Adjusted LCOE Model analysis and conveys the reasoning behind observed results. All observations made in this section of the report concern the output generated under the 'Central' Risk Premium Curves assumptions.

The equivalent results using the alternative curves are shown in Annex C although our initial assessment is that the general conclusions remain valid across all scenarios. We have also conducted model sensitivity analysis by varying the risk scoring and input parameters for each project. The results of this analysis are shown in Annex E.

5.1 Results of the LCOE model using a constant discount rate

As outlined in Section 3.2, the discount rate is a key input into any levelised cost calculation. Most traditional LCOE analysis uses a flat discount rate across projects (or at most a single discount rate for each technology).

As we are comparing three different project types, with differing cost assumptions it is useful to compare the LCOE with a flat discount rate to establish a baseline against which we can observe the impact of the risk weighting exercise. Table 5 below shows the P50 and P90 LCOE results for the three archetypal CCS projects assuming a 10% discount rate[19] for each technology.

Table 5 – Levelised Cost Of Electricity: Flat 10% discount rate

Calculation Components		Project A - Aire Valley	Project B - Humber Estuary	Project C - North-east England
		P50	P50	P50
CRF Components - Flat Rate	Discount Rate (%)	10.0%	10.0%	10.0%
	Project Lifetime (Years)	25	25	25
	Constructions Period (Years)	4	4	4
	CRF	0.1278	0.1278	0.1278
LCOE Calculation - Flat Rate	LCOE (£/MWh)	110.47	84.09	88.94

LCOE given a flat discount rate of 10%. CRF (Capex recovery factor) as defined in 3.2.2.1.

Project B has the lowest P50 (or expected) LCOE closely followed by Project C, with both projects having projected costs lower than £90/MWh. Project A has a much higher P50 LCOE than the other two projects at £110/MWh.

5.2 Results of the Risk-Adjusted LCOE calculation

One of the key issues with comparing LCOE values across flat discount rates is that does not deal well with varying levels of risk in projects. We have therefore reanalysed the

19 10% is a standard discount rate often used to examine medium to low risk investments – it is in line with the discount rate assumed for capture units in the UK CCS Cost Reduction Task Force Report.

three projects using an adjustment to the discount rate by project based on the level of apparent risk.

5.2.1 Results of P50 and P90 LCOE calculation using constant discount rates

The first stage of this process is to compare the projects using a constant 'low risk[20]' investment rate but examining not just the P50 expected LCOE but also the P90 LCOE that would result if, at each project, the relevant capex and opex overruns and technological issues came to pass. By comparing the resulting P90 numbers, in relation to the P50 levels we can create a proxy for the riskiness of a given project.

The results of the P50 and P90 analysis are shown in Table 6 below. Whilst Project B and Project C again have very low P50 levelised costs, Project A is around £20/MWh more expensive. However, when we compare the projects under P90 assumptions, Project B (£109/MWh) is still lower cost than Project A (£121/MWh) but Project C, our archetypal high risk project, has a much higher P90 LCOE at £168/MWh.

Table 6 – Low-risk LCOE results

Calculation Components		Project A - Aire Valley		Project B - Humber Estuary		Project C - North-east England	
		P50	P90	P50	P90	P50	P90
Capex Cost Total (£)		1,982,000,000	2,258,075,000	1,273,000,000	1,577,425,000	2,027,000,000	3,148,475,000
Capex Cost (£/kW)		3,166	3,607	1,480	1,834	2,777	4,313
Variable Costs (£/MWh)		30.74	35.58	48.52	60.14	26.19	35.12
Variable costs (£/kW)		224	231	353	334	191	168
LCOE Primary Components	Capex (£/MW)	3,166,134	3,607,149	1,480,233	1,834,215	2,776,712	4,312,979
	Fixed Opex (£/MW)	175,719	185,024	69,767	78,401	119,178	147,568
	Variable Cost (£/MW)	223,810	230,970	353,239	334,212	190,695	168,433
	Capacity Factor (%)	83.11%	74.1%	83.11%	63%	83%	55%
CRF Components - Low Risk Energy Investment Rate	Discount Rate (%)	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%
	Project Lifetime	25	25	25	25	25	25
	Constructions Period	4	4.5	4	5	4	8
	CRF	0.1003	0.1022	0.1003	0.1042	0.1003	0.1171
LCOE Calculation - Low Risk Rate	LCOE (£/MWh)	98.50	120.90	78.50	108.64	80.82	171.21

Low-risk LCOE calculations using a discount rate of 7.5%

Table 7 displays the resulting ratio of the P90 to P50 LCOE for each of the three archetypal projects. The ratios from the above table are calculated using the P50 and P90 LCOE values defined in Table 6. As expected the ratios increase for Projects A, B, and C respectively. This increment in ratios can be attributed to the risk levels assigned to each project from the model inputs. As the risk components of each project collectively increase, we would expect the overall volatility of the LCOE to increase. The substantially higher value for Project C is reflective of the non-linear nature of risks but also of the compound nature of project risks on the LCOE of a project. For example a performance risk with the capture block could lead to both higher capex costs as well as lower availability – the higher costs levels increase the LCOE in themselves but they are also spread over fewer hours of operation further compounding the increased P90 cost estimate.

20 We have assumed a 'Low-risk' rate equal to 7.5% which is equivalent to DECCs assumed hurdle rate for CCGTs.

Table 7 – LCOE low-risk P90/P50 ratios

Calculation Components	Project A - Aire Valley	Project B - Humber Estuary	Project C - North-east England
P90/P50 Ratio	1.23	1.38	2.15

P90/P50 ratios calculated under central assumptions utilising a discount rate of 7.5%

5.2.2 LCOE results with a risk adjusted discount rate

Taking the P90/P50 ratios and applying the risk adjustment curve as described in 3.3.1 we can calculate the risk premium to apply for each project – in this case the risk premium is the amount by which the generic 'Low-risk' discount rate should be adjusted to account for the additional risk in the project. Table 8 shows results from using the final risk adjusted discount rates to calculate a new P50 risk adjusted LCOE for each of our archetypal projects.

From Table 8 it is clear that the model is working as intended and assigning a higher adjusted discount rate to projects with a greater element of risk. However, despite having a higher level of risk than Project A and therefore demanding a higher rate of return, the expected LCOE of Project B is still the lowest of all three projects examined. Project C however now has the highest LCOE on a risk adjusted basis. These results are described further in section 5.3 below.

Table 8 – Risk-adjusted LCOE results*

Calculation Components		Project A - Aire Valley	Project B - Humber Estuary	Project C - North-east England
Risk Adjusted Components	P90/P50 Ratio	1.23	1.38	2.15
	Adjustment to Discount Rate	1.54%	3.79%	14.77%
	R adj. Discount Rate (%)	9.0%	11.3%	22.3%
	R adj. CRF	0.1168	0.1434	0.3107
Risk Adjusted LCOE	R adj. LCOE (£/MWh)	105.67	87.26	158.69

*Risk-adjusted LCOE values calculated by applying an adjusted discount rate using central assumptions

5.3 Results Summary and Conclusions

Summary of main results

Table 9 below shows a summary of the key project results taken from the Output sheet of the Risk Weighting LCOE model.

Table 9 – Summary of expected LCOE values for the Archetypal Projects

LCOE Summary Output table	Expected P50 LCOE (£/MWh 2013 money)		
Discount Rate	Project A - Aire Valley	Project B - Humber Estuary	Project C - North-east England
LCOE for Low Risk Rate [7.5%]	98.50	78.50	78.45
LCOE for Flat Rate [10%]	110.47	84.09	88.94
Risk Adjusted Discount Rate	9.0%	11.3%	22.3%
LCOE @ Risk Adjusted Discount Rate	105.67	87.26	158.69
Risk adj. Vs Flat Rate Ratio	0.96	1.04	1.78

Our low risk archetypal project, Project A, is the poorest performing project on a flat discount rate comparison. Therefore, on a simple LCOE analysis, it may be the least likely of our archetypal projects to realise project implementation. However, this comparison excludes the reality that higher discount rates would be required to attract finance for projects with a greater element of risk. Project A is defined as a low risk project based on a relatively established technology and feeding into a pre-exiting transport and storage system. Therefore, the calculated discount rate is favourable in comparison to the alternative projects. Consequently, the risk adjusted LCOE is more favourable for Project A than that of Project C despite having a much higher LCOE value at both 10% and 7.5% discount rates.

Project B has the lowest P50 LCOE assuming a flat 10% discount rate and, ignoring risk, may be considered generally more attractive than the alternative archetypal projects given the assumptions on capital and operational costs. Indeed even after accounting for its higher risk nature, Project B is still more attractive than Project A – this is partly a construct of the estimated costs but it also partially attributable to Project B being a gas based CCS plant. Megawatt for megawatt, the cost of building a gas fired power station is significantly lower than the costs involved in building a coal power station. As the discount rate exclusively affects the capex component of the LCOE equation, Project B is therefore less sensitive to an adjusted discount rate than an equivalent scale coal plant. The stable capex component of Project B, coupled with the project's already economically favourable specifications results in the risk adjusted LCOE being significantly lower than projects A and C.

Our archetypal high risk project, Project C, is the economically optimal project choice given a 7.5% discount rate using P50 values. However, the high level of risk involved in the project results in a significantly higher risk-adjusted discount rate, hence a substantially inflated risk-adjusted LCOE. The discount rate adjustment required is significantly higher than the medium/low risk projects with Project C demanding a discount rate of over double that of Project A. This is due in part to the non-linear nature of project risks (as shown in our survey results) but also due to the compound nature of certain project risks and their feed through into the P90 LCOE calculation.

Concluding Remarks

The project has been successful in delivering the key aims as set out in Section 2:

to build a coherent picture and evaluation framework for the risks associated with the development of an individual CCS project, supported by a model with which ETI can quantitatively evaluate alternative CCS projects from an investor's perspective.

Although this project has been focused on valuing risk, we have seen that while the P90/P50 ratio (which we are using as a proxy for that risk) is a major driver of the LCOE, it should not be the only consideration. Some decisions to drive down cost with only minor risk impacts (or where risks can be well mitigated) may well be 'worth it' to lower overall strike prices (evidenced by the LCOE of Project B, our medium risk project).

In addition, the available funding for projects of different risk/reward ratios is variable meaning that the overall capital cost of the project is an essential further consideration for project developers and policy designer. Indeed where the underlying risk is inherently high, such as when developing a new CCS cluster, taking a low capital cost approach to the capture side could have material additional benefits in terms of strike prices.

However it should also be noted that the results shown in this section are simply examples of the way in which the model can be used rather than an end point in themselves. In reality any new project being examined is likely to look like a combination of the choices for the three archetypal projects (rather than being an archetypal High/Medium/Low project itself). To date, he model has been populated with the three projects to illustrate the tool but it can be populated with real life project examples and used in other ways by ETI in the future. For example one alternative use of the model would be to use it to indicate potential key steps required to get a project category from a High risk to a Low risk score, and to estimate the value in doing so.

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6. HIGH-LEVEL VIEW OF THE FINANCIAL MODEL (STAGE 2)

This chapter introduces the objectives and key functionalities of the Financial Model that could be delivered under Stage 2 of the project.

6.1 Objectives

As mentioned earlier, the risk-adjusted LCOEs calculated in Stage 1 are a ‘first-cut’, or a proxy, for the strike prices required by the short-listed CCS projects. In order to produce a more accurate assessment of the strike prices, the level of sophistication needs to increase. From a simplified LCOE formula, the model needs to develop into an Investment Model using a Discounted Cash Flow (DCF) approach.

This would allow capturing elements, such as:

- Phased investments whereby a project has periods of time operating with and without a CfD (and potentially with and without CCS i.e. venting and paying carbon price for short periods of time);
- Specific draw-down (i.e. timing of payments) schedule for capital outflows;
- Changing fuel and carbon cost over the lifetime of the project;
- Cost-implications of basis risk (e.g. spread between the CfD reference price and the actual electricity price captured);
- Revenues after the CfD support period (incorporating a variable length CfD period);
- Generation without capture operating;
- Allowance for different discount rates for different parts of the projects (e.g. power station vs transport & storage)
- Associated with the different required discount rates, modelling of different regimes of charging/remunerating transport and storage (e.g. lump sum capex into DCF vs. a £/tCO2 opex charge with a ‘hold-harmless’ charging regime)

and in case of a High Level Project Finance Model:

- Effect of varying depreciation schedules;
- Tax implications;
- Working capital; and
- Financing structure.

During the Workshop 3, merits of the two options presented above were briefly discussed. A full-blown financial model, which is able to capture the tax and financing elements, has the advantage of representing more closely the reality of negotiations of an investment process. However, creating a sophisticated tool at such an early stage may not be the most appropriate approach to adopt. First, many of the assumptions that will need to be included in the modelling exercise remain highly uncertain and exposed to judgment of the users, secondly, potential equity investors and/or project financiers are likely to use their own financial modelling tools for evaluation purposes.

Based on initial conversations with ETI, it was therefore recognised that Stage 2 is predominantly a discovery phase of the second wave of CCS project economics. Any financial modelling tool should be tuned to support discussion with various financiers’ groups more than serving as a full valuation tool. Hence, for the purpose of this report we assumed that developing a Discounted Cash Flow model would be the preferred option for Stage 2. This remains open for discussion and it is ultimately up to ETI to decide on the scope of work.

6.2 Functionalities

The DCF Model would approach the evaluation of a CCS project on a pre-tax real terms basis, similarly to the LCOE calculation. The model will reproduce the expected stream of cash flows over the lifetime of the asset at an annual granularity[21] and it will calculate the strike price required by the project in order to hit the minimum required rate of return.

Should the comparative aspect across short-listed projects be important, the model can be designed to combine the modelling of cash flows of three projects in one single file. It could be built as a further extension to the existing LCOE model in order to maintain the risk-weighting and LCOE-based risk-adjusting functionalities.

6.2.1 User input stage

For each project the user will input into an input tab a number of general information and assumptions quantifying the physical characteristics of the project. In addition to those gathered in the LCOE Model, we would expect to require (but not limited to) the following:

- Duration of the various phases of the project, such as construction, commissioning, full operation under subsidy, post-subsidy operations, decommissioning, etc.. This includes also any sub-phase of the project itself, for instance a project initially built as a CCS-ready generation station and only subsequently converting into a CCS asset.
- Timing and amount of the capex payments – i.e. when the capex is expected to be paid over the construction phase and/or any subsequent periods.
- Timing and level of non-fuel opex cost.
- Annual volume of electricity produced (or underlying capacity factor, which incorporate dispatch patterns, planned and unplanned availability) and consistent volume of CO2 emitted vs captured.
- Annual expectation of fuel and carbon prices (hence cost to the project).
- Expectations of market power prices, hence CfD power indexation and interaction with the strike price as well as cost for access to the market (i.e. route to market).
- Project minimum rate of return. This could be aligned with the risk premium calculated in the LCOE Model based on the project risk metrics of the P90/P50 weighting exercise, but also differentiated by element (e.g. generation, capture, transport and storage).

6.2.2 Calculation stage

The calculation stage will reproduce line by line (i.e. item by item) the expected stream of negative (cost) and positive (revenue) annual cash flows over the economic lifetime of the asset based on the generic and project-specific input assumptions.

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21 Semi-annual or quarterly resolution is also adopted in asset valuation, but it would add a complexity, which is not necessarily justified at this stage.

A gross margin line (or EBITDA[22]) will be created by subtracting all the cost items from the revenue items on a year-by-year basis. In an income statement, this line represents the funds available before cost related to the amortisation plan of the asset, any tax or financing structure. Across the industry, this is generally calculated on a real basis, i.e. without accounting for the potential impact of inflation movements.

The aim of the model is to calculate the level of strike price required by the project to achieve the desired rate of return (or minimum rate of return). Therefore, a goal seek function will be set up so as to calculate the level of strike price that would produce a project NPV equal to zero.

An alternative is to goal seek the strike price so as to achieve an Internal Rate of Return equal to the minimum rate of return. The two methodologies are equivalent and could be built in parallel into the model, if requested.

Should the model split the generation, capture, transport and storage elements to apply a different minimum return, a four-tiered structure for the gross margin will be implemented to reflect this. The principle will however remain the same and the goal seek function will operate to achieve the four requested rates.

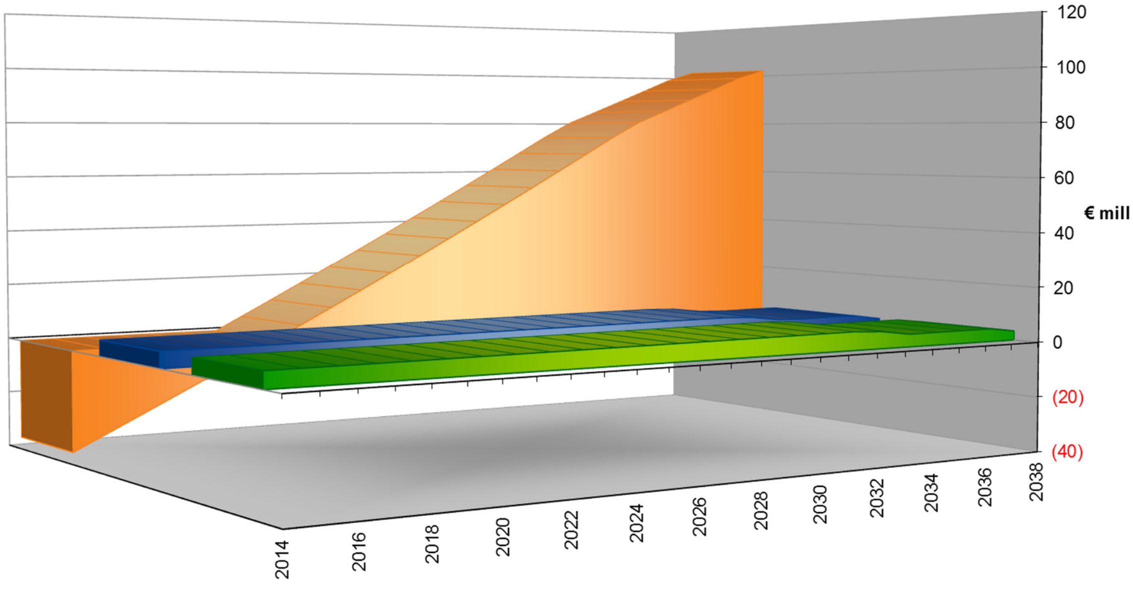
6.2.3 Output stage

The result sheet will be designed to present outputs on a comparative basis across the projects (if multiple are considered) and in a systematic manner. This is particularly important if the model is run to produce a number of sensitivity analyses.

A cash flow schedule could be graphically represented for each project (see example in Figure 10) as well as tornado diagrams showing the impact of various input assumptions on the requested CfD strike price.

22 Earnings Before Interest, Tax, Depreciation and Amortisation.

Figure 10 – Sample cash flows schedule based on project gross margin



ANNEX A – RESULTS OF QUESTIONNAIRES (WORKSHOP 2)

In this annex, we summarise the main findings from our questionnaires and the key comments which were made by our respondents.

A.1 Summary of results

Table 10 – Summary of construction risk responses; Conduit 1 capex overruns

Construction Risk - Conduit 1 Capex overruns

No.	Sub-category	High Risk Project							Low Risk Project								
		a. <5%	b. 5%-15%	c. 15%-30%	d. 30%-60%	e. 60%-100%	f. 100%-200%	Not sure	a. <5%	b. 5%-15%	c. 15%-30%	d. 30%-60%	e. 60%-100%	f. 100%-200%	Not sure	Mean	
1	Base generation block			3	3	1		1	2	5	1					3	c. 15%-30%
2	CO2 capture block			1	4	2		1		2	4				2	3	c. 15%-30%
3	Compressors & dehydration		2	5				1		5	1				2	2	b. 5%-15%
4	Gas conditioning equipment	2		2		2	1	1	2	3	1				2	3	c. 15%-30%
5	Electricity connection	1	3	2				2	4	3					1	2	b. 5%-15%
6	Fuel supply logistics	1	1	4	1			1	5	3						2	b. 5%-15%
7	Transport			2	4	1		1	3	3	2					3	c. 15%-30%
8	Storage		1		2	2	3		1	2	2	2			1	4	d. 30%-60%

Table 11 – Summary of construction risk responses; Conduit 2 delays

Construction Risk - Conduit 2 Delays

No.	Sub-category	High Risk Project							Low Risk Project								
		a. <3m	b. 3-6m	c. 6-12m	d. 12-24m	e. 24-48m	f. >48m	Not sure	a. <3m	b. 3-6m	c. 6-12m	d. 12-24m	e. 24-48m	f. >48m	Not sure	Mean	
1	Base generation block			4	2	1		2	2	5	1				1	3	c. 6-12m
2	CO2 capture block		1	1	5			2		4	2				3	3	c. 6-12m
3	Compressors & dehydration	2	3		2			2	4	2	0				3	2	b. 3-6m
4	Gas conditioning equipment	3	2	1	1			2	5	1					3	2	b. 3-6m
5	Electricity connection		3	1	3			2	6	2					1	2	b. 3-6m
6	Fuel supply logistics		3	1	3			2	6	2					1	2	b. 3-6m
7	Transport		1	2	2			4	4	1	1				3	2	b. 3-6m
8	Storage			2	1	2	2	2	2	2	1	1			3	3	c. 6-12m

N.B. For the risk associated with the gas conditioning equipment the mean value (when both high and low risk votes are considered) is greater than the mode for a high risk project. Therefore, we have adjusted the risk factor for a high risk project to match the value used in a medium risk project.

Table 12 – Summary of technology risk responses; Conduit 3 availability

Technology Risk - Conduit 3 Availability

No.	Sub-category	High Risk Project							Low Risk Project								
		a. 0%	b. <1%	c. 1%-3%	d. 3%-10%	e. 10%-25%	f. >25%	Not sure	a. 0%	b. <1%	c. 1%-3%	d. 3%-10%	e. 10%-25%	f. >25%	Not sure	Mean	
1	Base generation block		1		5	1		1		2	4	2				3	c. 1%-3%
2	CO2 capture block				4	3		1			6				2	4	d. 3%-10%
3	Compressors & dehydration			1	3	3		1	1	2	3				2	3	c. 1%-3%
4	Gas conditioning equipment		1	1	4			2	1	2	3	1			1	3	c. 1%-3%
5	Electricity connection	1	4	2				1	2	5		1				2	b. <1%
6	Fuel supply logistics		3	2	2			1	2	3	1				2	2	b. <1%
7	Transport		2	2	3			2	1	4	1	1				3	c. 1%-3%
8	Storage		1	1	3	3			1	1	2	2			2	4	d. 3%-10%
10	Overall CCS plant efficiency				5	2		1		1	4	1			2	4	d. 3%-10%

Table 13 – Summary of operational risk responses; Conduit 4 capex overruns

Operational Risk - Conduit 4 Opex overruns

No.	Sub-category	High Risk Project							Low Risk Project								
		a. <5%	b. 5%-15%	c. 15%-30%	d. 30%-60%	e. 60%-100%	f. 100%-200%	Not sure	a. <5%	b. 5%-15%	c. 15%-30%	d. 30%-60%	e. 60%-100%	f. 100%-200%	Not sure	Mean	
1	Base generation block		4	4					5	2	1					2	b. 5%-15%
2	CO2 capture block			4	3			1		4	2				2	3	c. 15%-30%
3	Compressors & dehydration	1	2	2		1		2	3	3					2	2	b. 5%-15%
4	Gas conditioning equipment	1	2	4				1	3	3					2	2	b. 5%-15%
5	Electricity connection	6		1				1	7	1						1	a. <5%
6	Transport	1	2	3	1			1	5	3						2	b. 5%-15%
7	Storage		1	2	4	1	1		3	3		1				3	c. 15%-30%

No.	Sub-category	a. 0%	b. 0%-3%	c. 3%-5%	d. 5%-20%	e. 20%-50%	f. >50%	Note sure	a. 0%	b. 0%-3%	c. 3%-5%	d. 5%-20%	e. 20%-50%	f. >50%	Not sure	Mean	
8	Electricity price captured*		1	4	1	1		1	1	2	2	2			1	3	c. 3%-5%
9	Delivered fuel price*		1	2		3	1	1	1	3		2			2	3	c. 3%-5%
10	EOR revenues*				1	2	2	3	2	1	1				4	4	d. 5%-20%
11	Dispatch*		2	3	2			1	2	2	1	1			2	3	c. 3%-5%

A.2 Review of key comments

Construction risk (1/2) – Conduit 1, Capex overrruns

Q1

Some respondents thought that the percentage overruns depended on competence; whilst CCGTs are a proven technology, coal plant built recently is more uncertain in a UIC context. Others agreed with this, saying that due to the highest capital content of the overall project, overruns would be high, due to exotic materials and labour prices. In addition, some felt that the design was sub-optimised for CCS running.

Q4

Respondents thought that due to some technologies requiring significant clean up, this would take a long time to fix. Therefore, the potential for overrun was high.

Q8

There is a high percentage of overrun due to the large number of high-cost, high risk unknowns. There is therefore a major cost to reconfigure. Whilst mitigation of risk is possible, this will come at significant risk. There may also be a need for more storage, assuming storage is not yet in use. There is also a possibility for needing twice as many wells.

Construction risk (2/2) – Conduit 2, delays to overall project completion

Q3

Whilst respondents agreed there should not be a complex fabrication issue, as it used relatively proven kit, one respondent believed that there was a risk of there being a long load time if it 'breaks'.

Q5

A few respondents agreed that it was unlikely that this would be on the critical path, and that any overruns would be a worst case scenario.

Q8

Respondents had the view that this was potentially complex politically, technically and on an organisational basis, as an entirely new site would be required, with one respondent of the view that this would potentially end the project.

Technology risk – Conduit 3, availability

None.

Operation risk – Conduit 4, Opex overruns

Q1

This is well understood, hence low percentages.

Q5

This is a low risk, so should be stable. It has a low importance, anyway.

Q7

One of the respondent assumed a much more difficult injection than envisaged, and dealing with leaks at the well head.

Q9

Respondents assumed no linkage between fuel cost drivers and CfD cost drivers, and hence, a high risk in a non-contract market, with the CfD not allowing for fuel prices. One respondent thought the overrun could be as much as 200% (or 50% on the upside)

Q10

Respondents appeared split on the risks, with one saying that it depended on whether the contract is take-or-pay or purely line dependent.

Q11

Respondents attributed a lower risk to this, with one remarking that a plant may choose not to dispatch if the final price is very high. However, a low risk plant would always dispatch. In contrast, another remarked that this assumes the plant will always dispatch, due to the CfD providing fixed price levels, regardless of the market price.

ANNEX B – RISK SUB-CATEGORY DETAILS

B.1 Siting, Engineering, Design & Operation and Operational Market Exposure

Table 14 – Sub category Risk Descriptions and key attributes

Description of category	Category – Key Attributes		
	Low Risk	**Medium Risk**	**High Risk**
Base generation block This includes all elements associated with a non-CCS power plant including boiler, turbines, generator, flue gas items, transformers etc.	Tried and tested, commercially available internationally standard base generation unit based on coal or gas (preferably applied in GB and paired with a CCS project previously)	Reasonably novel coal 'base' generation technology paired with	'Base' generation technology is novel and as such has little successfully operating real world installed capacity.
CO2 capture block This includes characteristics of amines (performance, degradation and disposal), absorbers, regenerator (post-comb), ASU (oxy-fuel) and gasifier/water-shift (pre-comb)	Technology chosen previously used on a large scale commercial CCS power project. Proven and verifiable performance track record of >2 years offering some performance guarantees	A capture approach with a track record at demo scale only so involves a significant scale increase. However, there are other developing projects currently developing the same technology which are more advanced than this project (so not first of a kind).	Capture approach relatively first of a kind and involves a significant scale increase (e.g. only previously tested at pilot/demo scale (<100MW)).
Compressors & dehydration block It includes dehydration of CO2, compression and pumping (including number of trains/redundancy) to the correct pressure for the pipeline network	Compression and dehydration using commercially sized products (i.e. a standard commercial offering) with sufficient redundancy built in to ensure specifications can be met and high levels of availability	Compression and dehydration using either new 'above-commercial' scale products or lean margins and low-in built redundancy in more standard offerings.	Compression and dehydration using new 'above-commercial' sized products and the push for a lean solution means low in-built redundancy and/or tight specification margins.
Other (including gas conditioning equipment) It includes acid gas treatment and conditioning required to produce CO2 of sufficient specification to be injected into the pipeline as well as other miscellaneous Capex costs	Other elements using commercially sized products with sufficient redundancy built in to ensure specifications can be met and high levels of availability	Other plant elements using either new 'above-commercial' scale products or lean margins and low-in built redundancy in more standard offerings.	Other elements of plant using new 'above-commercial' sized products and the push for a lean solution means low in-built redundancy and/or tight specification margins.
Electricity connection	Power station site is well	Power station site is	Power station site is

Description of category	Category – Key Attributes		
	Low Risk	**Medium Risk**	**High Risk**
This is the physical connection to the national grid network and supply power. It includes shallow connection charges, but excudes deep connection costs and wider system issues	located (<500m) for existing unutilised and sufficiently scaled electricity connection.	greenfield or brownfield but would require a new electricity connection. However suitable grid infrastructure is well located for the site (<500m) so even though reinforcement is required the link should not be High risk.	greenfield or brownfield but would require a new electricity connection and is at a significant distance from suitable grid infrastructure.
Fuel supply logistics This includes the arrangements for the physical supply of fuel to the site. Most likely by pipeline for gas and by port/rail for coal	Power station site is well located for a suitable fuel supply/connection point such that little new infrastructure is required.	Power station location has identified a new fuel supply/connection point at a reasonably close distance but there is some need for new infrastructure or reinforcement.	Power station location requires a new fuel supply/connection point with significant need for new infrastructure over a sizeable distance.
Transport This represents the transport system, including feeder lines into the main truck line	Chosen transport solution is an existing operational onshore pipeline with high reliability, low leakage and large spare capacity of multiple times required flow (low risk to fill pipe). Available potential feed-in point <5 miles from site.	Transport solution is an existing pipeline network with some spare capacity. However available potential feed-in point is either at a long-distance (~50 miles) from pipe or significant reinforcement of network elements is required entailing significant works.	Will develop a new dedicated onshore and offshore pipeline route.
Storage This represents the storage system as a whole, including site, offshore facility, wells & EOR related costs (if any)	Primary storage target operational, with high availability and low leakage with large volumes of spare capacity. Secondary store at least identified with high degree of certainty. Injectivity volumes available at storage site through currently under-utilised or pre-tested wells.	Either: Primary store is operational but spare capacity is limited and secondary store is not known with high degree of certainty. Or: Primary storage site has been identified and is very close to an existing operational store (which can potentially act as a secondary back-up and help characterise the new store).	Will develop a new offshore storage site outside of the Commercialisation Programme. Some EOR a possibility in future depending on storage solution.
Overall CCS plant efficiency i.e. efficiency, including parasitic load. P50 is 100%	Related to the overall risk from the main generation and capture risk-blocks. If a project has a low risks in the base generation, the CO2 capture block and the compressors/dehydration we would expect it to have a Low risk of overall efficiency issues etc.		

Description of category	Category – Key Attributes		
	Low Risk	**Medium Risk**	**High Risk**
expected figure. P90 is potential % decrease.			
Electricity price captured A CCS plant may not be able to capture exactly the legislated CfD reference (wholesale) price and achieve a price at discount to the benchmark. This sub-category therefore represents the percentage that is actually captured by the project via its selected route to market, including imbalance costs.	A clear established route-to-market for power with a PPA provider willing to match the CfD reference price and leaving no material imbalance exposure.	A clear established route-to-market for power with a PPA provider but only a partial match to the CfD reference price and some material residual imbalance exposure.	Unclear or unspecified route-to-market and no visible imbalance transfer to the offtaking party
Delivered fuel price This is the risk of fluctuations in delivered fuel price (incl. delivery charges/fees). P50 is 100% of the current Central view of the fuel price. P90 considers the hedging strategy, e.g. through structure of a fuel-indexed CfD or fuel supply agreement based on long-term fixed price, and it is measured as the increase in % points of fuel cost compared to the P50 view	Fuel purchase strategy leaves low risk to project from price fluctuations (e.g. accessing a long-run indexed price of fuel or having a fully fuel-linked CfD contract)	Either: Fuel purchase strategy based on spot market with only partial fuel-indexation in CfD contract Or: Fuel purchase strategy which has some longer-term hedging but does leave some market fuel price exposure	Fuel purchase strategy based on spot market (with no fuel-indexation in CfD contract)
EOR revenues The project may be reliant on additional revenues from the Enhance Oil Recovery process. This sub-category represents the risk of these revenues (or negative cost) of falling short of expectations. It is defined as the percentage of P50 reference scenario for EOR revenues (accounting for both price and volume). P90 is the decrease in % points from the Central view.	N/A' category option can be selected when there is no EOR planned (i.e. no risk but also no revenue). A Low risk EOR project would have some EOR revenue in the business case as an upside but would be attributing very little value in the P50 case and assuming full storage injectivity required as a back up.	EOR Revenue is included in the business case with either high volumes of CO2 being sent to EOR fields or a oil price exposure in the contract (but not both).	EOR Revenue is a large proportion of the P50 business case with high volumes of CO2 being sent to EOR fields. Contract for CO2 is linked to oil prices rather than on a fixed price term so both price and volume risk remain.
Dispatch	Related partially to a CCS plant's strike price (as this dictates their		

Description of category	Category – Key Attributes		
	Low Risk	Medium Risk	High Risk
This sub-category represents the risk for the project of not running whenever available, for instance when dispatched out by cheaper renewable generation. It is defined as the percentage of time that, when available, plant choses to dispatch because economics make sense	market bid price) but also crucially to the overall electricity market structure at the time of plant operation. Likely to be similar for all CCS plants (at least those that have a baseload CfD contract). A Low Risk project would have little danger (~1.5% under a P90 case) of being dispatched out by other generation over its lifetime. Medium and High Risk categories would have a P90 risk of ~4% reflecting a higher chance of being dispatched out by lower marginal cost generators renewables and nuclear competition.		

B.2 Ownership & Contractual

Ownership structure

This represents the complexity of the ownership structure, in particular the structure of the physical phases (generation/capture, transport and storage) of the project.

Owner creditworthiness

This sub-category pictures the perception of solvability and financial robustness of the project sponsor company.

Management team track-record / capability

This measures the capability of the project sponsor's team to deliver the CCS project and includes aspects, such as the local knowledge of industry and regulatory policies or the track records with previous (similar) projects, etc.

Contractual complexity

This refers to the legal chain of roles and responsibilities of parties involved (directly or indirectly) in the execution of different phases of the project, including post-commissioning.

Sub-contractor reliability

This refers to the reliability of various sub-contractors to deliver services in a timely manner, and meeting the specifications required by the contract.

Project attractiveness

This is a fully intangible aspect of a project. It also includes elements, such as the timing dimension of the development and completion phases, and how these feeds into the business cycle, and strategy of the sponsor company etc.

B.3 Policy & Regulatory, Permitting & Consents

Political and public support

This refers to a broad support for CCS projects, but not necessarily for a specific project.

Third-party access exemption

This refers to the Third-Party Access conditions that may be imposed on the project. We would expect that application of TPA is clear in general, and it is clear for a specific project (i.e. access to third-party existing pipe for a project relying on an existing network, or risk of obligation).

CfD framework

This refers to the legal framework of the Contract-for-Difference supporting scheme. It includes both commercial terms (e.g. strike price, reference price) and legal terms (e.g. clear T&Cs). We would generally expect that a CfD offer is secured by the project @FID.

Insurability

This refers to the ability and the conditions at which elements of the CCS chain can be insured. We would generally expect that all liability limits are clear and that appropriate insurance is available on reasonable terms for a CCS project to receive the green light from investors.

Long-term leakage liabilities

This refers to the existence and management of long-term leakage liabilities of the project sponsor. We would generally expect that these could be insured before handing over to the Government at a predefined point in time for a CCS project to receive the green light from investors.

Health & Safety

This sub-category includes all other aspects not mentioned in other categories that deal with Health & Safety issues. We would expect that rules are all defined and manageable for a CCS project to receive the green light from investors.

Permitting & Consents

This a broad sub-category regrouping all the various permits, consents and application processes to be obtain before starting the post-FEED, construction and operation phases of a CCS project. Failing to obtain any of these would result in a red flag decision of investors. Examples include land leases, AFL for offshore, grid connections, planning consent, DCO, etc.

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ANNEX C – GENERIC STAGE 1.A INPUT ASSUMPTIONS

Table 15 and Table 16 highlight our initial assumptions for a generic CCS project at a P50 level as agreed upon for Stage 1.a of the project.

C.1 P50 input assumptions based on a generic CCS project (1/2)

Table 15 – Generic CCS P50 input assumptions (1/2)

Sub-categories	Capex (GBP million)	Months (m) from FID to project completion	Availability based on unplanned outages (%)	Opex (GBP million per annum)
Base generation block	1,420	48	97%	52
CO2 capture block	360		95%	26
Compressors & dehydration block	160		100%	4
Gas conditioning equipment[23]	35		100%	1
Electricity connection	15		100%	1
Fuel supply logistics	30		100%	negligible
Transport	360		99%	7
Storage	220		99%	11

23 Now revised to be a category including gas conditioning equipment plus other miscellaneous components.

C.2 P50 input assumptions based on a generic CCS project (2/2)

Table 16 – Generic CCS P50 input assumptions (2/2)

Sub-categories	Planned availability or efficiency (%)	Percentage of reference price scenario
Overall planned project availability	90%	n.a.
Overall CCS plant efficiency	100%	n.a.
Electricity price captured	n.a.	98% of reference price
Delivered fuel price	n.a.	100% of Central view
EOR revenues	n.a.	100% of Central view
Dispatch	n.a.	100% of time when plant is available

ANNEX D – LCOE MODEL RESULTS: ALTERNATIVE RISK PREMIUM CURVES

D.1 Central Exponential Curve Results

Table 17 – LCOEs calculated under Central Exponential scenario assumptions

Calculation Components		Project A - Aire Valley P50	Project A - Aire Valley P90	Project B - Humber Estuary P50	Project B - Humber Estuary P90	Project C - North-east England P50	Project C - North-east England P90
LCOE Primary Components	Capex (£/MW)	3,166,134	3,607,149	1,480,233	1,834,215	2,776,712	4,312,979
	Fixed Opex (£/MW)	175,719	185,024	69,767	78,401	119,178	147,568
	Variable Cost (£/MW)	223,810	230,970	353,239	334,212	173,425	154,498
	Capacity Factor (%)	83.11%	74.1%	83.11%	63%	83%	55%
CRF Components - Low Risk Energy Investment Rate	Discount Rate (%)	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%
	Project Lifetime (Years)	25	25	25	25	25	25
	Constructions Period (Years)	4	4.5	4	5	4	8
	CRF	0.1003	0.1022	0.1003	0.1042	0.1003	0.1171
LCOE Calculation - Low Risk Rate	LCOE (£/MWh)	98.50	120.90	78.50	108.64	78.45	168.31
CRF Components - Flat Rate	Discount Rate (%)	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%
	Project Lifetime (Years)	25	25	25	25	25	25
	Constructions Period (Years)	4	5	4	5	4	8
	CRF	0.1278	0.1311	0.1278	0.1345	0.1278	0.1575
LCOE Calculation - Flat Rate	LCOE (£/MWh)	110.47	136.94	84.09	118.64	88.94	204.58
Risk Adjusted Components	P90/P50 Ratio	1.23		1.38		2.15	
	Adjustment to Discount Rate	1.46%		3.31%		19.37%	
	R adj. Discount Rate (%)	9.0%		10.8%		26.9%	
	R adj. CRF	0.1160		0.1375		0.3987	
Risk Adjusted LCOE	R adj. LCOE (£/MWh)	105.32		86.06		192.27	

D.2 High Curve Results

Table 18 – LCOEs calculated under High scenario assumptions

Calculation Components		Project A - Aire Valley		Project B - Humber Estuary		Project C - North-east England	
		P50	P90	P50	P90	P50	P90
LCOE Primary Components	Capex (£/MW)	3,166,134	3,607,149	1,480,233	1,834,215	2,776,712	4,312,979
	Fixed Opex (£/MW)	175,719	185,024	69,767	78,401	119,178	147,568
	Variable Cost (£/MW)	223,810	230,970	353,239	334,212	173,425	154,498
	Capacity Factor (%)	83.11%	74.1%	83.11%	63%	83%	55%
CRF Components - Low Risk Energy Investment Rate	Discount Rate (%)	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%
	Project Lifetime (Years)	25	25	25	25	25	25
	Constructions Period (Years)	4	4.5	4	5	4	8
	CRF	0.1003	0.1022	0.1003	0.1042	0.1003	0.1171
LCOE Calculation - Low Risk Rate	LCOE (£/MWh)	98.50	120.90	78.50	108.64	78.45	168.31
CRF Components - Flat Rate	Discount Rate (%)	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%
	Project Lifetime (Years)	25	25	25	25	25	25
	Constructions Period (Years)	4	5	4	5	4	8
	CRF	0.1278	0.1311	0.1278	0.1345	0.1278	0.1575
LCOE Calculation - Flat Rate	LCOE (£/MWh)	110.47	136.94	84.09	118.64	88.94	204.58
Risk Adjusted Components	P90/P50 Ratio	1.23		1.38		2.15	
	Adjustment to Discount Rate	2.94%		6.17%		21.84%	
	R adj. Discount Rate (%)	10.4%		13.7%		29.3%	
	R adj. CRF	0.1330		0.1744		0.4504	
Risk Adjusted LCOE	R adj. LCOE (£/MWh)	112.73		93.56		211.99	

D.3 Low Curve Results

Table 19 – LCOEs calculated under Low scenario assumptions

Calculation Components		Project A - Aire Valley		Project B - Humber Estuary		Project C - North-east England	
		P50	P90	P50	P90	P50	P90
LCOE Primary Components	Capex (£/MW)	3,166,134	3,607,149	1,480,233	1,834,215	2,776,712	4,312,979
	Fixed Opex (£/MW)	175,719	185,024	69,767	78,401	119,178	147,568
	Variable Cost (£/MW)	223,810	230,970	353,239	334,212	173,425	154,498
	Capacity Factor (%)	83.11%	74.1%	83.11%	63%	83%	55%
CRF Components - Low Risk Energy Investment Rate	Discount Rate (%)	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%
	Project Lifetime (Years)	25	25	25	25	25	25
	Constructions Period (Years)	4	4.5	4	5	4	8
	CRF	0.1003	0.1022	0.1003	0.1042	0.1003	0.1171
LCOE Calculation - Low Risk Rate	LCOE (£/MWh)	98.50	120.90	78.50	108.64	78.45	168.31
CRF Components - Flat Rate	Discount Rate (%)	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%
	Project Lifetime (Years)	25	25	25	25	25	25
	Constructions Period (Years)	4	5	4	5	4	8
	CRF	0.1278	0.1311	0.1278	0.1345	0.1278	0.1575
LCOE Calculation - Flat Rate	LCOE (£/MWh)	110.47	136.94	84.09	118.64	88.94	204.58
Risk Adjusted Components	P90/P50 Ratio	1.23		1.38		2.15	
	Adjustment to Discount Rate	0.78%		2.51%		10.95%	
	R adj. Discount Rate (%)	8.3%		10.0%		18.5%	
	R adj. CRF	0.1085		0.1280		0.2457	
Risk Adjusted LCOE	R adj. LCOE (£/MWh)	102.06		84.13		133.90	

ANNEX E – LCOE MODEL SENSITVITY ANALYSIS

To assess the robustness of the model, sensitivity analysis was performed on the risk conduits and key project inputs. Throughout this section the high scenario settings (i.e. increased risks or higher costs) are coloured in orange and the low scenario settings (i.e. decreased risks or lower costs) are coloured in blue.

E.1 Risk-conduit sensitivity analysis

For the risk-level sensitivity all risk conduits were initially defined as “medium” **for all projects** and the outturn risk adjusted-LCOE was recorded for each project (*N.B.* Project input parameters were key unchanged in this section of the sensitivity – see E.2 for project input sensitivity analysis). Each risk conduit was then set to “high” or “low” sequentially and the effect on the risk-adjusted LCOE was differenced from the “medium” (or, control) case. Subsequently tornado charts of the resulting risk adjusted LCOE for each project were produced as shown in Figure 11.

The sensitivity of the storage component for each plant is prominent in each of the three projects. From the questionnaire it was determined that the storage block would be a volatile component when exposed to high levels of risk, which is also true of the CO_2 capture block (another relatively sensitive component). For Project B the delivered fuel price is disproportionately sensitive to changes in the risk parameter in comparison with the alternative projects. This observation conforms to expectations as gas is a more expensive fuel (on a delivered energy basis), therefore the absolute value of gas required to meet generation is much higher than with a coal plant.

The ‘compressors and dehydration’ risk block shows up in the diagram only through an increase in cost. This is true as the medium and low risk categories for this category have the same P90 overrun potential, as outlined in Annex A. The opposite is observed for ‘Overall CCS Plant Efficiency’ and ‘Dispatch’ – for these risk categories the medium and high risk categories have the same P90 overrun potential and as such the impact is only shown though a decrease in LCOE.

Figure 11 – Risk conduit LCOE tornado charts – Risk Conduit Sensitivites

E.2 Project input sensitivity analysis

For the project input sensitivity analysis all project parameters were set as defined in Annex C (*N.B.* risk conduits remained unchanged throughout this sensitivity). Each parameter was then adjusted by ±10% sequentially and the effect on the risk-adjusted LCOE was differenced from the 'central' (control) case. Subsequently tornado charts of the resulting risk-adjusted LCOE for each project were produced as shown in Figure 12.

For the parameter definition sensitivity the most sensitive feature across all projects was the planned availability of the plant. The reason that this parameter is so important is that directly impacts the plants ability to generate revenue. For the similar reason we see that Dispatch is important – the dispatch parameter effectively acts as a multiplier for the length of time the plant is generating each year. In the control case this set to 100%, consequently, as the plant is dispatching continuously when available there is no more optimistic scenario resulting in a 'low' scenario LCOE difference of 0.

For the coal projects, A and C, Capex is also a definitively sensitive parameter as the absolute value is much higher than the gas project. The opposite is true for efficiency – it is much more important in Project B as the plant has higher overall fuel costs and has a greater starting efficiency as a gas project.

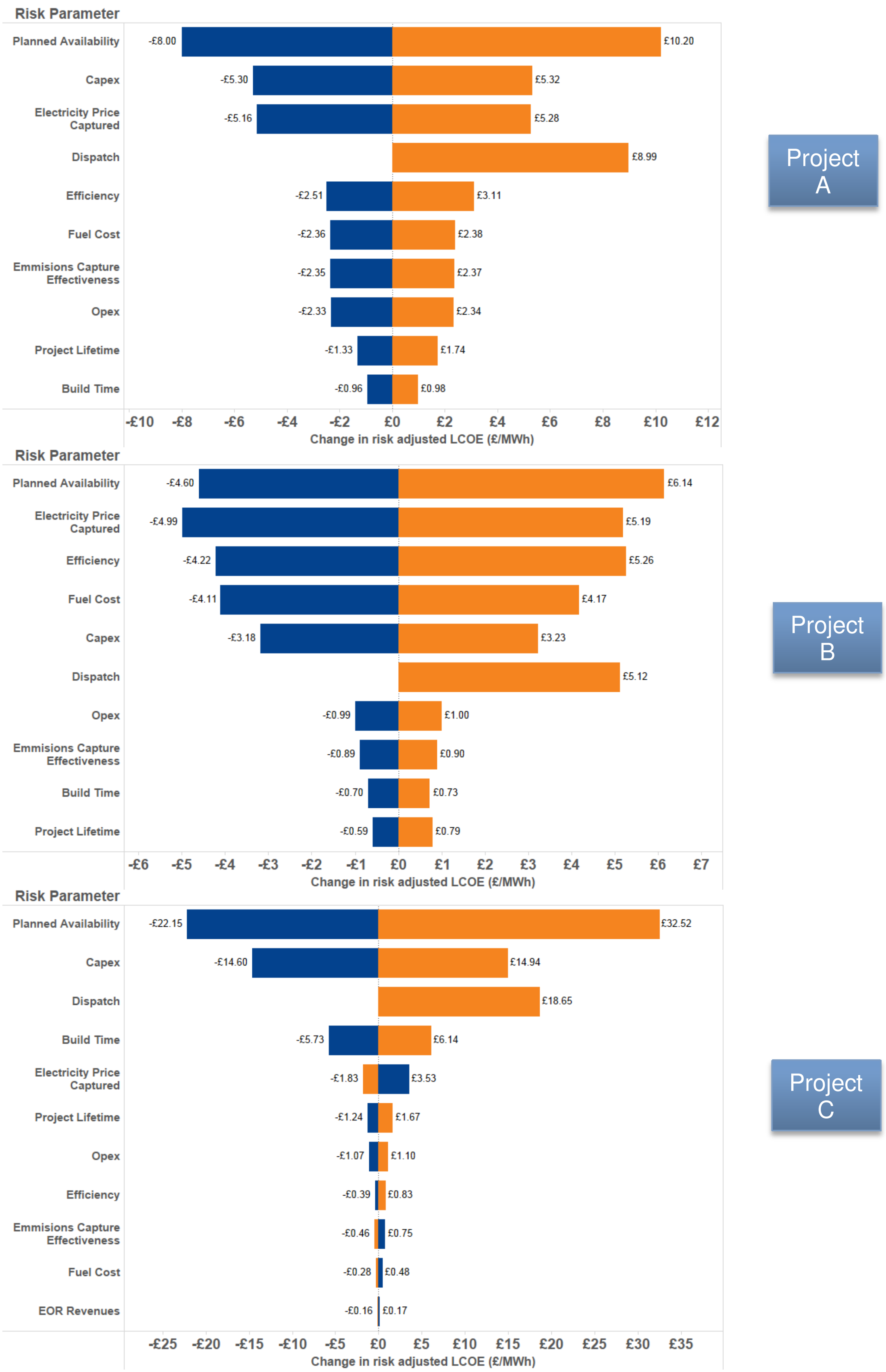
Finally it is worth noting the counter-intuitive results shown for some of the low importance project inputs in Project C. For 'Emission Capture Effectiveness' for example, we see that an increase in capture rate is actually leading to an increase in the cost (whereas the same change leads to a decrease in costs for the Project A and Project B). The logic for this is as follows:

- a rise in the capture rate decreases the non-risk-adjusted P50 LCOE which would, other things being equal lead to a fall in the risk-adjusted P50 (as we saw in Project A and Project B).
- However, it also decreases the non-risk weighted P90 LCOE. The P90 figure decreases by more in absolute terms that the P50 number but by less in proportional terms as the starting point for the non-risk adjusted P90 for Project C is already very high;
- This results in a higher P90/P50 ratio to feed into the risk adjustment calculation and therefore a slight increase in the discount rate applied to the risk-adjusted P50 LCOE.
- As the starting discount rate is so high (indeed in this example it is unrealistically high for Project C, probably rendering it unfinancable) the resulting risk adjusted LCOE is actually more sensitive to the P90/P50 ratio than it is to adjustments in the non-risk-weighted P50. This therefore leads to an overall increase in the cost for the risk-weighted LCOE, despite the assumed improvement in 'Emissions Capture Effectiveness'.

In effect, the project is slightly better off having higher expected costs with a greater level of certainty than it is having lower costs but with less certainty.

The analysis conducted shows that this counter intuitive behaviour only affects very small components of the LCOE in extremely risky (and therefore non-economically viable) projects.

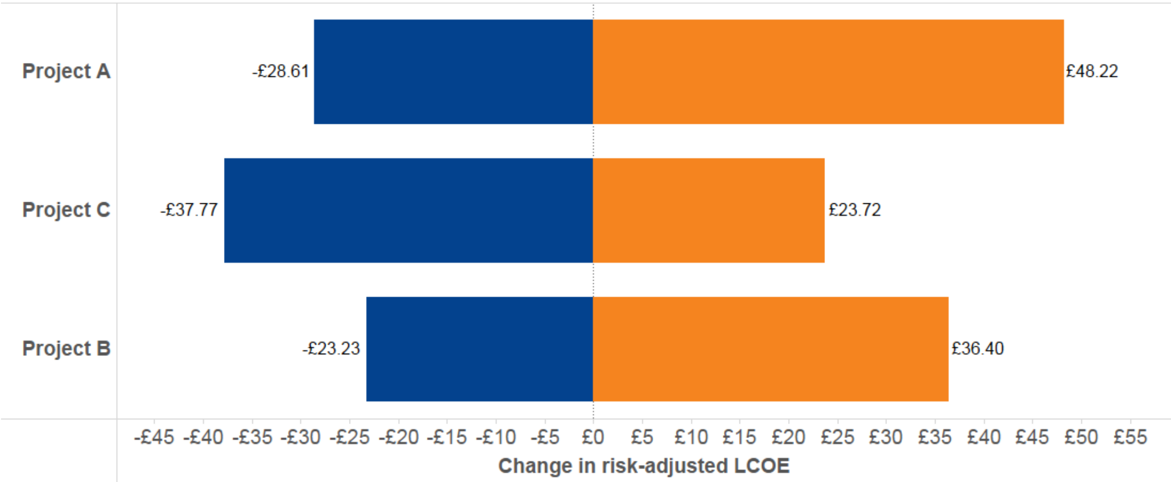
Figure 12 – Risk parameter LCOE tornado chart – Project Input Sensitivities



E.2.1 Scenario level parameter sensitivity

For the Scenario-level sensitivity all parameters were initially defined as described in Annex C and the risk-adjusted LCOE was recorded for each project (*N.B.* all risk conduits were left unchanged). All parameters were then adjusted by ±10% resulting in a 'best' (low) and 'worst' (high) case scenario (with respect to model parameters). The LCOEs output from each scenario were then differenced from the central (control) case. Subsequently a tornado chart was created to compare each project as shown below.

Figure 13 – Scenario level parameter sensitivity tornado chart



Risk-adjusted LCOE comparison by scenario

The projects most sensitive to changes in the risk parameters are, predictably, the coal plants. This is explained by the volatility in Capex costs. The coal plants percentile increments/decrements in project parameters outstrip the magnitude of the gas project resulting in a greater sensitivity to changes in those project parameters.

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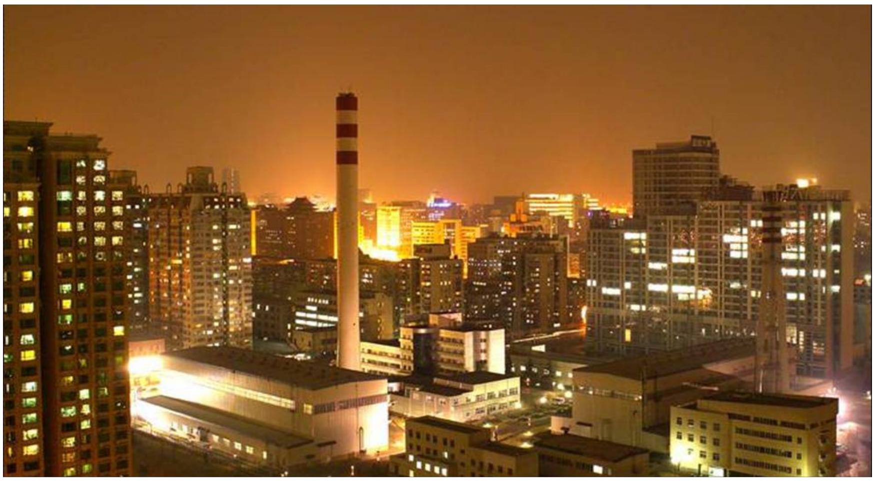

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