Aberthaw Power Station

NOx BAT Options Appraisal – July 2017

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Contents

1. Introduction

This document has been produced in response to a Schedule 5 notice issued by Natural Resources Wales (NRW) on 28th June 2017 in relation to a permit variation application to allow Aberthaw Power Station to widen the range of coals it can burn to include higher volatile matter coals (HVMCs). This document supercedes previous Best Available Techniques (BAT) options appraisals submitted for this variation. The focus is on providing a justification for BAT as part of the application for the permit variation, though for completeness an Appendix considers abatement options under expected future regulatory requirements.

2. Context for Aberthaw

As decarbonisation progresses in the UK Aberthaw's role continues to change, with a future of reducing load factors and an increasing focus on providing generation at times of high demand. This change in focus means that going forwards the power station running is likely to comprise of more unpredictable short duration, intermittent periods of operation.

Aberthaw's remaining lifetime as a security of supply plant is driven by the pace with which the UK electricity system decarbonises. There is inevitably large uncertainty associated with this due to the dependency on the timescales for renewables growth, nuclear new-build, closure of existing nuclear and the delivery of new CCGTs. However, currently the expectation is that Aberthaw will still have an important role to play in supporting security of supply until the mid 2020's. The Government have consulted on plans to phase out unabated coal-fired power stations by the end of 2025 at the latest, though the outcome of this consultation has yet to be published.

3. Regulatory Context and Sector BAT

The Industrial Emissions Directive (IED) specifies Emission Limit Values (ELVs) for combustion plant, with less onerous limits specified for plant which operate for less than 1500 hours per annum. Aberthaw is currently in the UK's Transitional National Plan (TNP). The purpose of the Transitional National Plan (TNP) is to give plants time to transition to IED compliance, under the conditions and environmental safeguards specified in the IED, with compliance with the IED ELVs required after the TNP ends on 30th June 2020. The safeguards include compliance with Environmental Quality Standards (Article 18), the "no backsliding" condition (Article 32(2)) and the general obligation for BAT to be applied (Article 11). The definition of BAT in the IED explicitly recognises the need for techniques to be economically and technically viable.

The BAT conclusion for existing pulverised coal plant (>300MW_{th}) proposed in the 2006 LCPD BREF[1] is a combination of primary measures (such as air and fuel staging and low NO_x burners, reburning

[1] European Commission 2006

etc.) in combination with SCR or combined techniques to achieve an emission level of 90-200 mg/Nm^3. The document is clear that these values are not proposed as emission limit values, as the determination of appropriate permit conditions needs to take into account local and site-specific factors such as the technical characteristics of the installation concerned, its geographical location and the local environmental conditions. The 2006 BREF also notes that the economic and technical viability of upgrading existing installations needs to be taken into account.

Updated BAT conclusions for European combustion plant have very recently been finalised with approval granted at the Article 75 Committee in April 2017 but these have not yet been published. Under IED, BAT conclusions which have gone through Article 75 approval are required to be implemented into permits four years after publication in the Official Journal of the European Union (OJEU).

To provide clarity to the sector NRW and the Environment Agency set out their position on BAT in England and Wales in the "IED BAT ESI Review Paper" finalised in 2014. The paper covers the period from 1st January 2016 until the implementation of the new BAT conclusions. The focus is on identiftying the ELVs below which plant has demonstrated that they can operate when applying the techniques considered to represent BAT. This paper sets out the principles to be used to determine BAT as:

1. *The ELVs will be based on existing performance data and will be demonstrably no worse than current performance i.e. no backsliding.*
2. *The ELVS cannot exceed those ELVs required by the LCPD as on 31st Dec 2015.*
3. *The ELVs will be as close as is practicable to the agreed sector ELVs, based on the applicable criteria.*
4. *Mixed techniques can be considered as BAT.*
5. *Under mixed techniques it is expected that operators will ensure units with the lowest emissions are operated in preference to those with higher emissions.*
6. *BAT considers the nature of the releases as well as cost & benefit.*
7. *BAT will reflect the future of the site i.e. if it is due to close under the Limited Life Derogation (LLD) or if it is upgrading under the TNP.*

Although this document sets out generic sector ELVs for coal-fired power stations there is explicit recognition that site-specific determinations are appropriate for some power stations:

"The characteristics of the majority of coal stations that will operate after 2015 are sufficiently similar that it is appropriate to set sector wide limits as described above. However, there are a number of coal stations which have unique characteristics that have a sufficiently significant impact on emissions performance that site specific limits are appropriate. We will consider these separately, applying the relevant criteria in the IED."

The document details the sector NOx ELVs for coal-fired plant derived from the subset of similar UK plants (i.e. excluding Aberthaw) as 450 mg/Nm^3 for the monthly average and 550 mg/Nm^3 for the 95th percentile of daily averages. The approach taken to derive these levels was to use historical data from 2010 to 2012 to identify the levels below which plants have demonstrated they can operate when applying the techniques considered to be BAT.

The Schedule 5 notice issued by NRW on 28th June 2017 references these values as the starting point for the NOx BAT determination for Aberthaw Power Station. However, it is appropriate for BAT at Aberthaw to be derived on a site specific basis using the principles set out in the sector BAT document, given that:

- Aberthaw has a completely different design to the plant used to derive the sector ELVs;
- data from Aberthaw were not part of the derivation of the sector ELV for NOx;
- the document recognises that site-specific approaches should be used for some plant;
- a site-specific approach has been used for other coal plant and all CCGTs.

Although Aberthaw is undergoing a conversion to burn high volatile matter coal, this conversion does not alter the fundamentally different design of Aberthaw, which is considered further in Section 4.

4. Technical characteristics of Aberthaw

Aberthaw has a very unusual plant design, with downshot boilers designed to fire local, low volatile Welsh coals. It is the only plant in the UK with this design and there are very few other plant of this design elsewhere in Europe. The downshot boilers operate at higher temperatures and have longer combustion residence times than other plant, resulting in higher concentrations of thermal NOx. It is therefore technically more difficult and costly for Aberthaw to achieve the same NOx emissions performance as other conventional coal-fired plant. For example, for other UK coal plant Low NOx Burners (LNB) with over fire air (OFA) are typically used as a primary abatement measure. This is a mature technology with many designs currently available from worldwide suppliers adapted to each type and size of boiler.

The downshot firing arrangement at Aberthaw means that it is not technically feasible (or prohibitively expensive[2]) to fit conventional LNB to the plant due to:

- the geometry of Aberthaw's firing system;
- extensive rearrangement of boiler structure and tubing to accommodate the new burners;
- removal of Aberthaw's current secondary air system and rerouting of air to the LNBs;
- modifications to Pulverised Fuel and Milling plant to accommodate LNBs.

[2] Prohibitively expensive compared to the costs and reductions offered by Low NOx Boiler Technology

Low NOx Boiler Technology (LNBo) is a primary measure which has been installed on Unit 9 at Aberthaw. As this technology is more unique than Low NOx Burners, there are a limited number of suppliers and it has higher costs. The BREF / Task Force on Techno-Economic Issues[3] (TFTEI) figures indicate costs of £4 – 7m a unit for LNB, approximately 25-50% of the LNBo cost (Unit 9 installed cost was ~£15.2m). LNBo is also much more complex to install with significant costs incurred from a much longer outage time.

5. Potential Abatement Options

This section describes the NOx abatement options which could be deployed at Aberthaw to reduce NOx concentrations. The assessment includes all potential technologies which might reduce concentrations and gives reasons if these techniques are not applicable at Aberthaw. The cost-benefit assessment has included sensitivity assessments where appropriate and the basis of the assumptions used for sensitivity tests are also included in this section.

5.1. Options Considered not Feasible for Aberthaw

The following options have been considered both in previous assessments and in this review but due to various reasons detailed below are not feasible for use at Aberthaw.

5.1.1. Low NOx Burners

Low NOx burners are a primary NOx reduction technique widely installed on power stations. These reduce NOx emissions through staging of air or fuel to the burner. This is a mature technology with many designs currently available from worldwide suppliers adapted to each type and size of boiler.

Aberthaw has a vertical firing arrangement which is not compatible with conventional Low NOx burner technology. As noted in Section 4 major plant changes would be necessary to the secondary air system in order to accommodate Low NOx burners, such that Low NOx Boiler Technology would be a more cost effective option.

5.1.2. Flue Gas Recirculation

Flue gas recirculation (FGR) directs a proportion of the flue gas back to the combustion chamber which dilutes the oxygen concentration in the combustion air. This process cools the flame temperature and also limits the supply of oxygen for nitrogen oxidation thus limiting NOx generation.

[3] Task Force on Techno Economic Issues: Estimation of Costs of Reduction Techniques for LCP Methodology, Table 15
http://tftei.citepa.org/images/files/2016-02-11/TFTEI_cost_calculation%20methodology_2015_05_28.pdf

Gas for this process is typically taken from the flue gas stream after it has passed through the airheaters but before the ESPs. For application at Aberthaw the FGR system would require the installation of a new fan to recirculate approximately 30% of the flue gas back into the secondary air system. A dust collection device would be required before the fan and new ductwork to supply flue gas from the fan to Aberthaw's forced draught system. Retrofitting an existing system with flue gas recirculation presents some adaption difficulties due to the efficiency losses of both the boiler and the burners (except when recirculating small volumes of flue gas).

The reduction of oxygen at the burner will make combustion inherently more unstable. Aberthaw's burners do not have a stabilised rooted flame this makes the application of FGR high risk for Aberthaw. Due to the safety implications of this technology it is not considered further.

5.1.3. Fuel Staging (Reburn)

Fuel staging, also termed reburning, is based on the creation of different zones in the furnace by the staged injection of fuel and air. The aim is to reduce the nitrogen oxides back to nitrogen. Reburn consists of three zones:

- Primary combustion zone: 80-85% of the fuel by heat is burnt in this zone in an oxidising or slightly reducing atmosphere.
- Secondary combustion zone: secondary fuel is injected into a reducing atmosphere. Hydrocarbon radicals are produced reacting with nitrogen oxides which were formed in the primary zone.
- Third combustion zone: combustion is completed through the addition of air.

Various fuels may be used for burnout but typically natural gas is used due to the ability to achieve lower NOx than coal or fuel oil. Application of this technology to Aberthaw would entail:

- reducing the overall combustion air to the burner through the existing secondary air system;
- installation of a number of gas burners above the burner arch which would supply ~20% of the overall thermal input to the boiler in addition;
- modification of the existing secondary air system to supply combustion air to the secondary and burnout zone.

This option is not considered feasible for Aberthaw as:

- Aberthaw does not have a gas supply of suitable capacity for reburning. A gas connection to the power station would have significant cost (>£50M);
- The additional gas burn at ~20% of thermal input would have significant cost;

- carbon in ash would be adversely effected by reburning as the primary zone will be sub stoichimetric. Aberthaw's carbon in ash is already high so any increase may have significant impact on ESP performance and consequently dust emissions;
- the technique is not proven for down-shot boilers with the risk of reduced flame stability presenting a major safety hazard.

5.1.4. Unit Derate

Aberthaw's NOx emissions increase with load due to higher thermal NOx from the increased thermal input to the boiler. This option considers derating units 7 and 8 to reduce NOx emissions, a derate of Unit 9 will be less feasible as this unit has a smaller increase of NOx with load (see figures below). Historically NOx on Units 7 & 8 firing low volatile matter (VM) coal has been approximately 20% higher at full load than at part load.

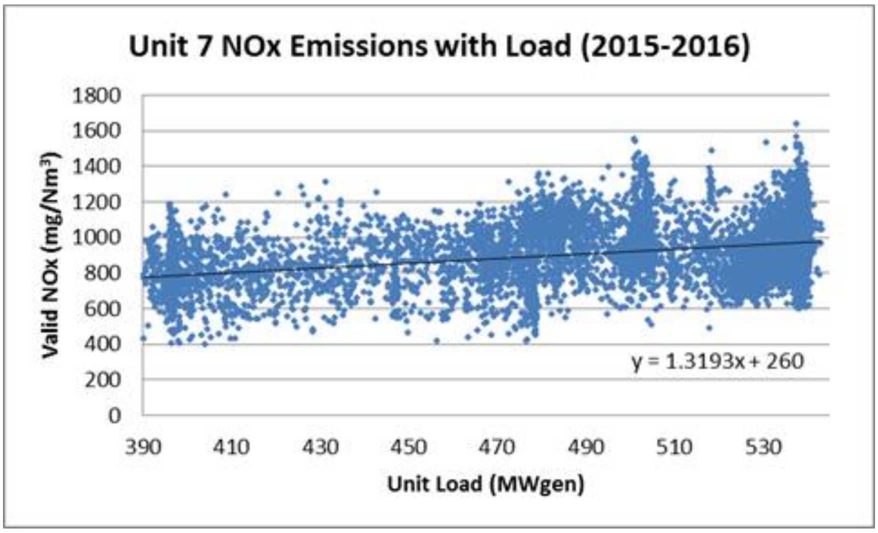

Figure 5.1.4a Variation in hourly average NOx concentrations with load for Unit 7.(Unit 8 would show similar variation)

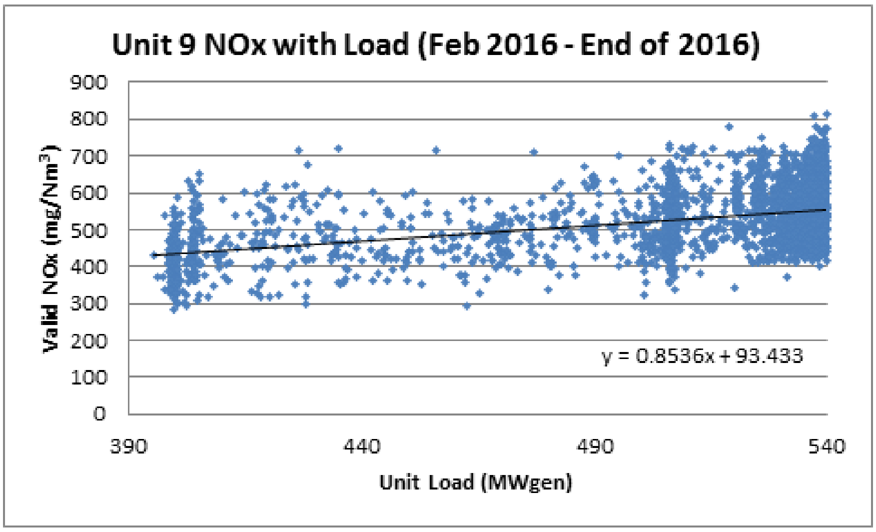

Figure 5.1.4b Variation in hourly average NOx concentrations with load for Unit 9

It is not considered possible to reduce the maximum load of the unit to the Stable Export Limit as this would make the unit completely inflexible and would have significant impact on the operation of the units. To demonstrate the influence of load reduction on emissions a reduction of 5% to 494Mwso (26MW lower than current MEL of 520MWso) would result in 4% lower concentration of NOx compared to that at part load. In reality NOx emissions would not be improved to this extent as in the base case the units will at times run below full load. This option is not seen as a viable option in its own right and is therefore not considered further within this assessment.

5.2. Primary Measures with Low VM Coal Options

The following considers NOx abatement options for Aberthaw's units whilst continuing to fire low VM coal.

5.2.1. Baseline NOx Emissions

In this case the units continue to operate firing low volatile matter coal. Units 7 and 8 utilise Thermal Input Biasing and Unit 9 is operated with the currently installed Low NOx Boiler Technology. The Schedule 5 notice issued by NRW on 28th June 2017 asks for a sensitivity analysis with LNBo performance on LVM coal of 400-450 mg/Nm^3. However, operational data shows that emissions have been higher than these values. The numbers in Table 5.2.1 reflect Unit 9's optimised NOx emissions performance at full load from September 2016 - July 2017. Unit 7 and 8 data are recent historical averages at full load.

Unit	NOx (mg/Nm^3) Range	NOx (mg/Nm^3) Typical
7	940-1000	970
8	940-1000	970
9	500-530	515
Station Average	**793-843**	**818**

Table 5.2.1. Baseline Unit NOx Emissions

5.2.2. Windbox Plate Modifications

The following considers Units 7 and 8 operating on Low VM coal with the installation of windbox plates. These plates are installed to bias more combustion air to the lower furnace and therefore increase the staging of the combustion. Capital costs for this modification is approximately £20k per unit. For the BAT assessment both units 7 and 8 are assumed to acheive 800mg/Nm^3.

Unit	Modification	Baseline NOx (mg/Nm^3)	NOx (mg/Nm^3) Range	NOx (mg/Nm^3) Typical	Capital Cost (£m)	Operating Cost (£m)
7	LVM + Windbox	970	780-820	800	0.02	-
8	LVM + Windbox	970	780-820	800	0.02	-
9	None	515	500-530	515	0	-
Station Average		**818**	**687-723**	**705**	**0.04**	**-**

Table 5.2.2. Windbox plate modification NOx Emissions

Due to the low capital cost of installation of the windbox plates this option is considered to be installed for each further options applied to Units 7 and 8.

5.2.3. Full Low NOx Boiler Technology (LNBo) on Units 7 and 8

This option involves the modification of Aberthaw's combustion system on Unit 7 and 8 to that which has been installed on Unit 9. The retrofit of LNBo on Units 7 and 8 would require the installation of pulverised fuel cyclones and vents, over-fired air and additional dampers to allow improved control of combustion air flow. This technology reduces NOx formation from combustion of coal by staging air to the furnace. In this option the station continues to fire Low Volatile coals.

The cost and time for installation of a low NOx boiler unit are well understood as Unit 9 has been upgraded with this technology. The cost of upgrading Unit 9 was £15.2m with an outage of approximately 7 months (this was significantly longer than expected due to the complexity of the installation). The difference in the cost of operating an LNBo converted unit compared to an unmodified unit is assumed to be negligible. The LNBo conversion of Unit 9 has reduced NOx emissions by ~35% compared to Unit 7 and 8.

Unit	Modification	Baseline NOx (mg/Nm^3)	NOx (mg/Nm^3) Range	NOx (mg/Nm^3) Typical	Capital Cost (£m)	Operating Cost (£m)
7	LVM + LNBo	970	500-530	515	15.2	-
8	LVM + LNBo	970	500-530	515	15.2	-
9	None	515	500-530	515	-	-
Station value		**818**	**500-530**	**515**	**30.4**	**-**

Table 5.2.3: Assumed costs and abatement of further installation of LNBo technology

5.2.4. LNBo Light Option

As a sensitivity a lower capex low NOx Boiler Technology option has been assessed with continued firing of low VM coal. The option considered in this scenario is full LNBo installation but without the installation of PF cyclones – this is referred to LNBo Light. The scope of this option includes a coal preheat system and an Over Fired Air (OFA) system. The removal of PF cyclones from the LNBo system would reduce the cost of installation but also the expected NOx abatement of the system.

The LNBo (full LNBo) solution installed at Aberthaw at Unit 9 as reflected in Table 5.2.3 was known to be a proven option prior to its installation from its deployment on another plant in Europe. The lower cost reduced scope LNBo options, including LNBo Light, investigated by RWE are not commercially proven.

The cost of the reduced scope LNBo is based on information received from a potential supplier for the installation of LNBo without cyclones. The cost of this option is ~20% less than full LNBo installation but with poorer NOx abatement on low VM coal. The supplier expected NOx values for this option were based on supplier's expected performance and operational experience of the full LNBo conversion on Unit 9. The supplier considered that this option would increase Carbon in Ash by 1% and has been included in the operating costs. The assumptions for this sensitivity case are given in Table 5.2.4.

Unit	Modification	Baseline NOx (mg/Nm^3)	NOx (mg/Nm^3) Range	NOx (mg/Nm^3) Typical	Capital Cost (£m)	Operating Cost (£m)
7	LVM + LNBo Light	970	530-658	594	12.6	0.07
8	LVM + LNBo Light	970	530-658	594	12.6	0.07
9	None	515	500-530	515	-	-
Station value		**818**	**520-615**	**568**	**25.2**	**0.14**

Table 5.2.4 Sensitivity assessment of the costs and benefits of a lower capex, lower abatement installation of LNBo technology – not proven.

5.2.5. Over Fired Air Only on Units 7 and 8

This option considers the installation of Over Fired Air on the front and rear walls of Units 7 and 8 without the installation of PF cyclones or a coal preheat system (as on Unit 9). Each unit is assumed to continue to fire low volatile coal. The application of OFA without preheat or PF cyclones has not been applied to other downshot fired power stations it is therefore unproven technology. There would be significant risk of combustion instability on the units whilst firing low volatile coals, posing a process safety risk.

RWE requested information from a potential supplier on the costs and anticipated performance of such an option, the following provides a summary of the the information received:

- approximately 40% less expensive than Full LNBo conversion;
- supplier expected at best NOx emissions of $675mg/Nm^3$ on Low VM coal with ~$200mg/Nm^3$ higher CO, 2% higher Carbon in Ash on low VM coal.

Table 5.2.5 summarises the assumptions used for the assessment, with the range based on operating experience of full LNBo on Unit 9. The operating cost of this option has been calculated from the increase in carbon in ash.

Unit	Modification	Baseline NOx (mg/Nm^3)	NOx (mg/Nm^3) Range	NOx (mg/Nm^3) Typical	Capital Cost (£m)	Operating Cost (£m)
7	LVM +OFA only	970	675-803	739	9.4	0.14
8	LVM +OFA only	970	675-803	739	9.4	0.14
9	None	515	500-530	515	-	-
Station value		**818**	**617-712**	**664**	**18.9**	**0.28**

Table 5.2.5 Sensitivity assessment of the costs and benefits of Over Fired Air Only – not proven.

5.3. Selective Non-Catalytic Reduction (SNCR)

This option considers the installation of windbox modifications on Unit 7 and 8 followed by the installation of SNCR on all units.

Selective non-catalytic reduction relies on a reaction between ammonia and nitrogen oxide (NO) in an appropriate temperature window for an appropriate amount of time to convert the ammonia and nitrogen oxide to water vapour and nitrogen. Water diluted urea solution is typically used for SNCR installed on large coal fired units. The temperature window for effective NOx removal is 800˚C to 1050˚C and optimally 1000˚C for urea based systems. Exceeding 1050˚C will cause reagent to thermally dissociate preventing the reduction of NOx. If the temperature is lower than 800˚C the DeNOx reaction will not occur causing the reagent to “slip” unreacted with the flue gas. Reagent injection rate is normally limited to prevent slip exceeding 5 to 10ppm.

SNCR systems typically have a number of injectors spread across the width of a boiler. Injectors would need to be installed in levels to introduce urea into the boiler at the correct temperature (as the position of the temperature window changes with boiler load). A uniform NOx and urea distribution within the temperature window is key to achieving good NOx reduction.

Temperature measurements taken at Aberthaw have indicated that position of the flue gas temperature window at full load for SNCR (900˚C to 1100˚C) exists at the middle of the secondary superheater. An SNCR system would need to inject reagent from the front wall of the boiler through the platen superheater banks (which have a pitch of approximately 70cm) to react with NOx 10m from its point of injection. The location of the temperature window for SNCR at Aberthaw makes the process more complex than other plants.

Aberthaw has 36 pulverised coal burners on unit which can be individually fired, the vast majority of other PF plants will operate mills with all burners in service. This means that a wide range of firing patterns exist at Aberthaw compared to other PF plants. NOx will be formed locally to the burners which are in service and therefore NOx formation will not be uniform across the furnace but stratified according to the firing pattern. An effective SNCR requires NOx and reagent to be well distributed at the correct temperature window. SNCR suppliers typically model firing configurations to predict where NOx will be formed, injection rates of reagent are varied to target when NOx has been predicted to exist. Due to the wide range of firing configurations at Aberthaw this approach may not be practical. The localised concentrations of NOx formed at Aberthaw will also be difficult to target even if they can be identified.

Aberthaw's future running regime is likely to be highly flexible to enable generation to be provided at times of peak demand. Flexible operation will move the temperature window for SNCR, making it difficult to target. This will increase ammonia slip and decrease the removal efficiency of an SNCR system.

Table 3.27 of the draft updated BREF[4] states that SNCR typically achieves NOx reduction of 30-50% from baseline levels on large coal fired units but performance is highly dependent on operating conditions. The TFTEI details that the NOx removal efficiency of SNCR decreases with rising plant sizes due to injection and mixing constraints. For plants >700MWth (each Aberthaw unit is ~1300MWth) a maximum removal efficiency of 35% is provided by the TFTEI. Given the complexity of operating this technology at Aberthaw a removal range of 25-35% was used for evaluation with a typical removal of 30%.

TFTEI's Emission Reduction Investment and Cost Calculation[5] provides a range of SNCR capital cost of 11.2€/kWth – 20€/kWth (9.8-17.4 £/kWth) with an average value of 15.6€/kWth (13.6 £/kWth). This equates to a range of £13.0-23.3m per Aberthaw unit with an average value of £18.2m per Aberthaw unit.

The average TFTEI capital cost has been used for the cost-benefit assessment and Table 5.3 summarises the assumptions used. Operating costs were based on a price of urea of 175 £/tonne for 40% solution and a 1.1:1 normalised urea to NOx stoichiometry. This option applies SNCR and windbox plates in combination and assumes continued low VM operation.

[4] Best Available Techniques Reference Document for Large Combustion Plant. Final Draft (June 2016).
[5]TFTEI's ERICCa (Emission Reduction Investment and Cost Calculation) Reduction Measures in LCPs Calculation tool provides an average costs for SNCR in EUR /kWth

Unit	Modification	Baseline NOx (mg/Nm^3)	NOx (mg/Nm^3) Range	NOx (mg/Nm^3) Typical	Capital Cost (£m)	Operating Cost @ 1500 hours (£m/yr)
7	LVM + SNCR	970	507-615	560	18.2	0.75
8	LVM + SNCR	970	507-615	560	18.2	0.75
9	LVM + SNCR	515	325-398	361	18.2	0.51
Station value		**818**	**446-543**	**494**	**54.6**	**1.7**

Table 5.3 Assumed costs and abatement for installation of SNCR .

5.4. Selective Catalytic Reduction with Low VM Operation

This option considers the continued operation of the units on low VM coal but with the installation of Selective Catalytic Reduction (SCR). SCR uses ammonia to reduce oxides of nitrogen to nitrogen and water vapour, in this process a catalyst is used to facilitate the reaction. SCR is a well-developed secondary measure for reducing NOx emissions on coal fired power plants.

The SCR process injects ammonia into the flue-gas upstream of the catalyst. NOx conversion takes place on the catalyst's surface at a temperature between 300°C and 450°C. SCRs are typically designed to achieve 90% reduction of baseline NOx emissions. RWE explored an SCR option for Aberthaw Power Station, this option included:

- installation of a three layer catalyst in a high dust environment before the plant's air-heaters;
- removal of a section of the economiser before the SCR to raise the temperature of the flue gases in the SCR to facilitate the reaction;
- reinstallation of the removed section of the economiser after the SCR;
- ammonia injection and flue gas mixing devices before the SCR;
- rerouting of ductwork to and from the SCR;
- installation of new mill air-heaters on each unit (this was required so that no flue gas would bypass the SCR). These new mill air-heaters would use treated flue gas after the SCR.

Tenders received in 2012 for the SCR system at Aberthaw were >£200million for three units (~£70m per unit), though these tenders were specified to reduce NOx from a baseline of 1200mg/Nm^3 to 200mg/Nm^3.

For the basis of this assessment SCR costs are based on 46.7€/kWth (the average SCR cost form the TFTEI, at this cost SCR would cost approximately £54m per Aberthaw unit) In this option two SCR systems are installed on both Units 7 and 8 , as these are the units with the highest unabated NOx applying DeNOx technology to these units will provide the greatest cost benefit. Opex was based on a cost of anhydrous ammonia of £480/tonne.

Unit	Modification	Baseline NOx (mg/Nm^3)	NOx (mg/Nm^3) Range	NOx (mg/Nm^3) Typical	Capital Cost (£m)	Operating Cost @ 1500 hours (£m/yr)
7	LVM + SCR	970	78-123	80	54	0.75
8	LVM + SCR	970	78-123	80	54	0.75
9	None	515	500-530	515	-	-
Station value		**818**	**219-259**	**225**	**108**	**1.5**

Table 5.4 Assumed costs and abatement for installation of SCR

5.4.1. Hybrid SCR with Low VM Operation

Hybrid SCR combines SNCR with a catalyst to utilise reagent which has not reacted within the SNCR temperature window. In this arrangement a smaller SCR system is needed which can reduce the capital cost of the system.

The combination of the two technologies enables the $DeNO_x$ reagent to be injected at the boiler in a slightly lower temperature window, avoiding thermal degradation of reagent and reagent loss. Also, the SNCR removal performance can be boosted because the reagent leakage is allowed to rise dramatically rather than being limited to between 5ppm and 10ppm. As the partially NO_x reduced flue gas of high ammonia content is discharged from the boiler it is passed over a catalyst that promotes further reaction with the ammonia present. This mops up the ammonia to a low residual slippage, approximately 2ppm to 5ppm and increases the NO_x removed. The amount of catalyst used is much lower than that associated with a full SCR plant. This permits the use of smaller reactors; it is common practise to make the reactors even smaller by operating them with low residence time (this reduces the overall NO_x abatement performance to below that of SCR but still achieving better than 50% abatement).

At Aberthaw it may be possible to install a catalyst between the economiser exit and the air heater inlet, this would require the expansion of ductwork to lower flue gas velocities through the catalyst and obtain sufficient residence time. Current post economiser gas temperatures are ~320°C at Aberthaw, this is at the low end of the acceptable range for SCR, limiting the performance of the SCR as well as increasing the risk of ammonium bisulphate formation which is an Airheater fouling concern. The application of this option to Aberthaw would have similar issues as the SNCR option.

The cost of this option is based on the average cost for installation of a full SNCR system (£18m, per unit) plus the installation of a single layer of SCR catalyst, which is assumed to cost one third of a full SCR system (£18m per unit). Operating costs are estimated from the cost of an SNCR system plus half the fixed cost of a full SCR (using TFTEI's Emission Reduction Investment and Cost Calculation – ERICCa[3]). A NOx reduction of 65-70% is assumed to be achieved when this technology is applied to Unit 7 and 8.

Unit	Modification	Baseline NOx (mg/Nm^3)	NOx (mg/Nm^3) Range	NOx (mg/Nm^3) Typical	Capital Cost (£m)	Operating Cost @ 1500 hours (£m/yr)
7	LVM + Hybrid SCR	970	234-287	240	36.2	0.87
8	LVM + Hybrid SCR	970	234-287	240	36.2	0.87
9	None	515	500-530	515	-	-
Station value		**818**	**323-368**	**332**	**72.4**	**1.7**

Table 5.4.1 Assumed costs and abatement for installation of Hybrid SCR.

5.5. Conversion to High Volatile Coal

This option assumes all units are converted to fire higher volatile coals, Units 7 and 8 utilise Thermal Input Biasing with windbox plates and Unit 9 is operated with the currently installed Low NOx Boiler technology.

A conversion to high volatile coal primarily consists of safety features to detect coal fires and contain milling plant explosions which will enable Aberthaw to safely burn high volatile coals. An explosion detection and supression system would be required on the milling plant and PF system to contain explosions should they occur (due to the more explosive nature of higer volatile fuel). Changes to the control system would be necessary on all units in addition to the upgrade of Unit 7 and 8's Boiler Management System to the higher integrity Boiler Safety System to align with Unit 9 upgrade already in place. The total cost to upgrade the station to enable the burning of high volatile fuel would be be approximately £6.5m. It is not expected that there would be any significant change in the operating costs of the station following the conversion to higher volatile coal.

Estimated NOx performance whilst firing high volatile coals is in the range 500-630mg/Nm^3 (typically 550mg/Nm^3) on Units 7 and 8 and 305-370mg/Nm^3 (typically 340mg/Nm^3) on Unit 9 at full load. The Schedule 5 issued by Natural Resources Wales (NRW) on 28th June 2017 asked for sensitivity analysis on LNBo performance based on 300 mg/ Nm^3, however this is considered slightly optimistic and a value of 305 mg/ Nm^3 has been used as the low end of the range.

Table 5.5 provides the station's NOx emissions from the station with a breakdown of NOx across the three units. In practice the emission concentrations will vary depending on the fuel diet.

Unit	Modification	Baseline NOx (mg/Nm3)	NOx (mg/Nm^3) Range	NOx (mg/Nm^3) Typical	Capital Cost (£m)	Operating Cost (£m)
7	HiVM + Windbox	970	500-630	550	2.15	-
8	HiVM + Windbox	970	500-630	550	2.15	-
9	HiVM	515	305-370	340	2.15	-
Station Average		**818**	**435-543**	**480**	**6.45**	**-**

Table 5.5. Estimated Average NOx Emissions at full load on High VM Coal.

5.6. Further installation of Low NOx Boiler Technology with High VM Coal

This section considers the potential to install additional primary measures to reduce NOx on Units 7 and 8.

5.6.1. Full Low NOx Boiler on Units 7 and 8 and High VM Coal

This option involves the modification of Aberthaw's combustion system on Unit 7 and 8 to that which has been installed on Unit 9. The retrofit of LNBo on Units 7 and 8 would require the installation of pulverised fuel cyclones and vents, over-fired air and additional dampers to allow improved control of combustion air flow.

Unit	Modification	Baseline NOx (mg/Nm^3)	NOx (mg/Nm^3) Range	NOx (mg/Nm^3) Typical	Capital Cost (£m)	Operating Cost (£m)
7	HiVM+ LNBo	970	305-370	340	17.35	-
8	HiVM+ LNBo	970	305-370	340	17.35	-
9	HiVM	515	305-370	340	2.15	-
Station value		**818**	**305-370**	**340**	**36.85**	**-**

Table 5.6.1: Assumed costs and abatement of further installation of LNBo technology

5.6.2. LNBo Light Option and Hi VM Coal

This option considers LNBo installation but without the installation of PF cyclones following the conversion of all units to high VM coal.

The cost of the reduced scope LNBo is based on information received from a potential supplier for installation of LNBo without cyclones. The cost of this option is ~20% cheaper than full LNBo installation and NOx emissions are reduced by ~20% compared to Windbox modifications only.

Unit	Modification	Baseline NOx (mg/Nm³)	NOx (mg/Nm³) Range	NOx (mg/Nm³) Typical	Capital Cost (£m)	Operating Cost (£m)
7	HiVM + LNBo light	970	390-492	441	14.8	0.07
8	HiVM + LNBo light	970	390-492	441	14.8	0.07
9	HiVM	515	305-370	340	2.15	-
Station value		**818**	**362-451**	**407**	**31.7**	**0.14**

Table 5.6.2. Sensitivity assessment of the costs and benefits of a lower capex, lower abatement installation of LNBo technology – not proven.

5.6.3. Over Fired Air Only on Units 7 and 8

This option considers the installation of Over Fired Air on the front and rear walls of Units 7 and 8 without the installation of PF cyclones or a coal preheat system (as on Unit 9). Each unit is also converted to fire high volatile coal.

RWE requested information from a potential supplier on the costs and anticipated performance of such an option, the following provides a summary of the the information received:

- approximately 40% less expensive than Full LNBo conversion;
- approximately 15% lower emissions than the windbox plates only.

The operating cost of this option has been calculated from the increase in carbon in ash.

Unit	Modification	Baseline NOx (mg/Nm³)	NOx (mg/Nm³) Range	NOx (mg/Nm³) Typical	Capital Cost (£m)	Operating Cost (£m)
7	HiVM + OFA only	970	450-552	501	11.6	0.14
8	HiVM + OFA only	970	450-552	501	11.6	0.14
9	HiVM	515	305-370	340	2.15	-
Station value		**818**	**402-491**	**447**	**25.3**	**0.28**

Table 5.6.3. Sensitivity assessment of the costs and benefits of Over Fired Air Only – not proven.

5.7. Selective Catalytic Reduction

In this option, the station is converted to high VM coal and two SCR systems are installed on both Units 7 and 8, as these are the units with the highest unabated NOx applying DeNOx technology to these units will provide the greatest cost benefit. The cost of an SCR for this option has been assumed to be lower due to the lower NOx from Units 7 and 8 following the conversion to high VM coal. Costs from a lower baseline NOx were estimated using the TFTEI's Emission Reduction Investment and Cost Calculation (costs for SCR 30.8-52.8€/kWth, average 46.7€/kWth).

Unit	Modification	Baseline NOx (mg/Nm^3)	NOx (mg/Nm^3) Range	NOx (mg/Nm^3) Typical	Capital Cost (£m)	Operating Cost @ 1500 hours (£m/yr)
7	HiVM + SCR	970	50-95	55	56.2	0.58
8	HiVM + SCR	970	50-95	55	56.2	0.58
9	None	515	305-370	340	2.15	-
Station value		**818**	**135-186**	**150**	**114.5**	**1.16**

Table 5.7. Assumed costs and abatement for installation of SCR.

5.8. Selective Non-Catalytic Reduction

This option considers the installation of Selective Non-Catalytic Reduction on the highest NOx units (Units 7 and 8) after the conversion to high VM coal as these are the units with the highest unabated NOx applying SNCR technology to these units will provide the greatest cost benefit. Each SNCR is assumed to achieve an abatement in the range 25-35%.

Unit	Modification	Baseline NOx (mg/Nm^3)	NOx (mg/Nm^3) Range	NOx (mg/Nm^3) Typical	Capital Cost (£m)	Operating Cost @ 1500 hours (£m/yr)
7	HiVM+ SNCR	970	325-473	385	20.4	0.54
8	HiVM+ SNCR	970	325-473	385	20.4	0.54
9	HiVM	515	305-370	340	2.15	
Station value		**818**	**318-438**	**370**	**42.9**	**1.1**

Table 5.8. Assumed costs and abatement of SNCR.

5.9. Hybrid Selective Catalytic Reduction

This option considers the installation of a hybrid Selective Catalytic Reduction system on the highest NOx units – Units 7 and 8 after the conversion to high VM coal as these are the units with the highest unabated NOx applying Hybrid SCR technology to these units will provide the greatest cost benefit. Each Hybrid SCR is assumed to achieve an abatement of 65-70%.

Unit	Modification	Baseline NOx (mg/Nm^3)	NOx (mg/Nm^3) Range	NOx (mg/Nm^3) Typical	Capital Cost (£m)	Operating Cost @ 1500 hours (£m/yr)
7	HiVM+ Hybrid SCR	970	150-221	165	38.4	0.7
8	HiVM+ Hybrid SCR	970	150-221	165	38.4	0.7
9	HiVM	515	150-221	340	2.15	
Station value		**818**	**202-270**	**223**	**78.9**	**1.3**

Table 5.9 Assumed costs and abatement of Hybrid SCR

6. Assessment of costs and benefits of abatement options

6.1. Scope of analysis

Cost benefit analysis has been performed for the abatement options described in Section 5. The scope of the analysis has been restricted to the costs and benefits of NOx abatement. Although for some technologies there are secondary benefits and disbenefits (for example ammonia slip) the impact of these is much smaller than those of NOx as the primary pollutant being considered. These factors do not need detailed consideration when it can be demonstrated that the costs far outweigh the benefits. The costs of being unavailable for the installation time have also not been considered - for some of the options (eg low NOx Boiler installation) this is likely to be very significant.

6.2. Methodology & Assumptions

The Net Present Value (NPV) cost per mg/Nm^3 of NOx reduced has been calculated for all the feasible options detailed in Section 5. The calculations have been performed using the NPV calculation in Excel with a discount rate of 8.5% and the capital and operating costs indicated in the sections above and a station lifetime until 2025. The cost of capital has not been included in the analysis. The approach used has been chosen to provide a consistent measure of abatement cost across all the options considered, allowing them to be compared in a relative sense. The cost of the abatement options has been related to reductions in emission concentrations and not mass emissions so are independent of load factor.

6.3. Results and discussion of cost-benefit assessment

Table A1 in Appendix A summarises the reduction in emission concentrations and the costs of each abatement option and this is also shown graphically in Figure 6.3.1 below.

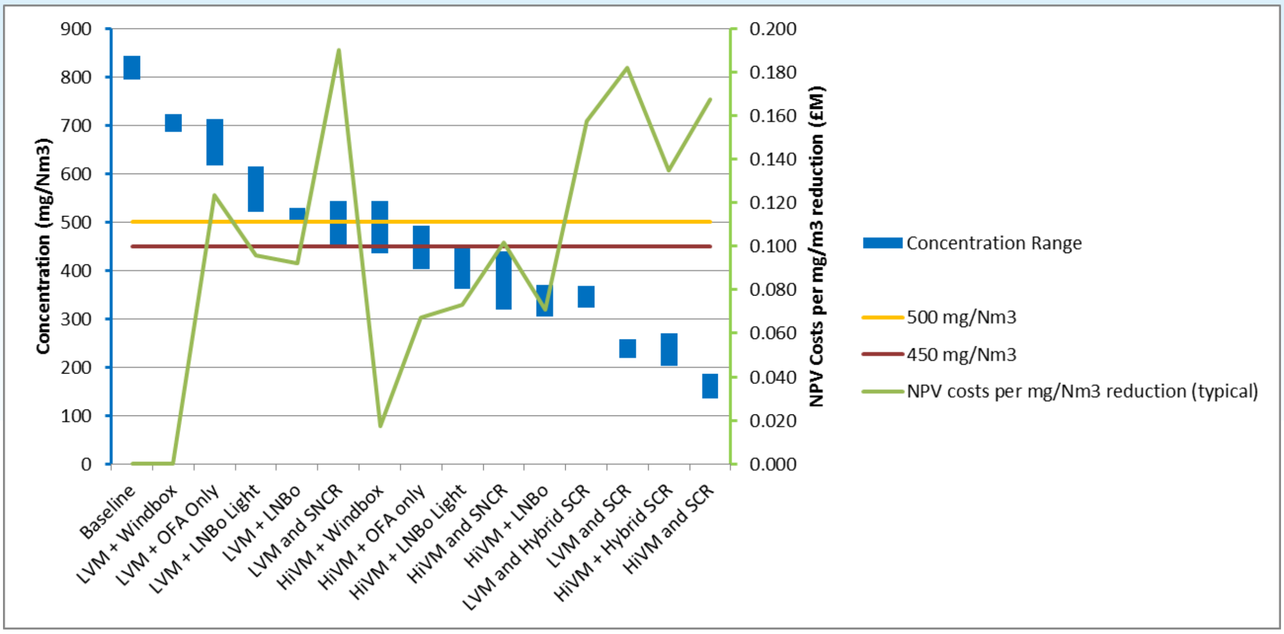

Figure 6.3.1 Costs per mg/Nm^3 of potential NOx abatement options at Aberthaw Power Station and associated emission ranges.

Figure 6.3.1 shows that with exception of LVM + SCR and LVM+Hybrid SCR, only the HiVM options offer emissions after optimisation down to the 450 mg/Nm^3 level required by IED for TNP plant from mid 2020. Figure 6.3.1 also illustrates that HiVM conversion is the most cost-effective option for reducing NOx emissions. Therefore, the HiVM options have been examined in more detail. Figure 6.3.2 below show the costs of the abatement options plotted against the difference in NOx emission concentration from the baseline.

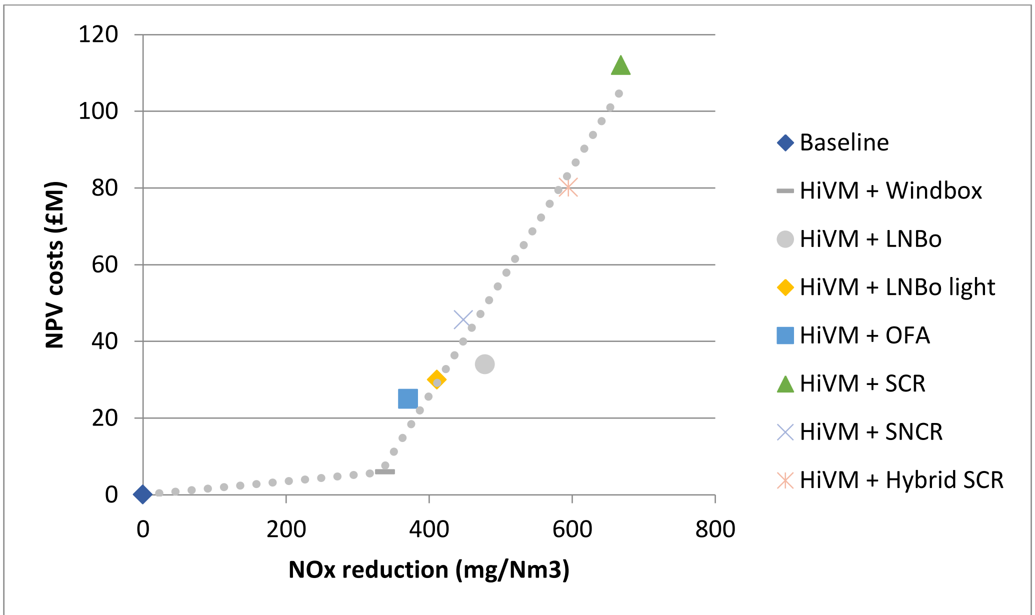

Figure 6.3.2. NOx reductions (mg/Nm^3) of potential NOx abatement options at Aberthaw Power Station and associated costs.

This shows that there is a step change in the cost effectiveness of the abatement options beyond HiVM and windbox technology. Although the other options offer higher emission reductions they are substantially more expensive for the reduction offered, as illustrated by the large change in gradient of the line on Figure 6.3.2.

Therefore, noting that the assessment of BAT needs to take into account costs and benefits in the context of the changing role of the plant (significantly reduced load factors and limited lifetime) it is considered that the conversion to high volatile fuel together with windbox modifications represents BAT for NOx abatement at Aberthaw.

Currently there is only a limited amount of data available on NOx performance and as per Table 5.5 and Figure 6.3.1, a range of NOx emissions between 435 and 543 mg/Nm^3 is expected using HiVM + windbox technology. RWE is committed to meeting the current monthly Environmental Permit limit of 500mg/Nm^3 but will need operational time to understand plant performance and to optimise emissions towards the lower end of the expected range.

7. Implications of updated BAT conclusions

Section 3 noted that updated BAT conclusions have recently been approved but not yet published. For completeness the costs and benefits of the abatement options has been considered against these new requirements in Appendix B. This assessment demonstrates that further abatement from 2021 (beyond conversion to high volatile coal and windbox technology installation) is disproportionately costly compared to the environmental benefits.

8. Assessment of Environmental Impact of NOx Emissions

Air dispersion modelling has previously been carried out to assess the impact of NOx emissions from Aberthaw on local ground level concentrations[6]. This assessment modelled operation at a range of load factors and emissions including those above the current permit limit of 500 mg/Nm^3. For all scenarios the predicted impacts are well below the relevant Air Quality Standards.

There has been extensive monitoring of ambient air quality around Aberthaw, with one of the monitoring sites located in the area in which the highest impacts from the power station would be expected. This has demonstrated[7] that since monitoring commenced in 2002 measured NO_2 concentrations have consistently been well below all the relevant Air Quality Standards. Both NOx emission concentrations and load factors have reduced significantly since the monitoring finished in 2015.

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[6] Aberthaw Low NOx Boilers: Air Impact Assessment. Report ENV/687/2015.
[7] Aberthaw Air Quality Management Plan Review March 2015.

9. Conclusions

The costs and benefits of all potential NOx abatement options at Aberthaw Power Station have been assessed. The analysis has demonstrated that the most cost effective option for reducing NOx emissions is the conversion to higher volatile matter coals with the installation of Windbox technology onto Units 7 and 8 and this is considered to represent BAT. With further optimisation this option has the potential to achieve the IED limit of 450 mg/Nm^3 by the end of the TNP in mid 2020. Given the ongoing market changes described in Section 2 and the likely low operating hours and lifetime of Aberthaw any further abatement options are considered to be disproportionate to the benefits. For completeness the costs and benefits of further abatement for the period after 2021 have also been considered against the updated BAT conclusions expected to be published shortly. This assessment also demonstrates that further abatement is very disproportionate to the environmental benefits.

Appendix A: Summary of NOx abatement options.

Fuel	Option	NOx reduction mg/Nm^3 (typical)	NPV costs (£M)	NPV costs per mg/Nm^3 reduction (£M)
Baseline	818 mg/Nm^3	0	0	0
	Windbox (U7&8)	113	0.04	0.0003
	OFA Only (U7&8)	154	19.0	0.123
	LNBo Light (U7&8)	251	24.05	0.096
LVM +	LNBo (U7&8)	303	28.02	0.092
	SNCR (U7&8)	324	61.7	0.190
	Hybrid SCR (U7&8)	486	76.6	0.157
	SCR (U7&8)	593	108	0.182
	Windbox (U7&8)	338	5.94	0.018
	OFA only (U7&8)	371	24.94	0.067
	LNBo Light (U7&8)	411	29.99	0.073
HiVM +	LNBo (U7&8)	478	33.96	0.071
	SNCR (U7&8)	448	45.61	0.102
	Hybrid SCR (U7&8)	595	80.15	0.135
	SCR (U7&8)	668	112.01	0.168

Table A.1 Data for BAT Options Appraisal

Appendix B : Assessment of NOx abatement options for Aberthaw for the post BREF period

B1. Introduction

In April 2017 updated European Commission BAT conclusions for Large Combustion Plant (BREF) were approved at the Article 75 Committee, though these have yet to be formally published. To ensure that the assessment of potential abatement options is as a comprehensive as possible a further cost benefit assessment has been performed against these new requirements.

B2. Plant context

As noted in the main part of the report Aberthaw has a limited lifetime, but the length of its remaining life is uncertain as it depends on market and policy drivers associated with the pace of the decarbonisation of the UK electricity system. The Government has recently consulted on plans to phase out coal fired generation by the end of 2025 at the latest, but the outcome of this consultation has not yet been published. However, even without this Government intervention both market drivers and the expected technical lifetime of the plant (~2028) mean that the plant has a very limited lifetime following BREF implementation, particularly in the context of normal investment cycles for large combustion plant. Aberthaw's focus during its remaining lifetime is on providing generation at times of high demand to support security of supply, and therefore future generation patterns are expected to be increasingly intermittent.

Aberthaw's particular technical characteristics are also relevant to the assessment of BAT. Section 4 of the main report describes the unusual plant design (downshot boilers) and the reasons why it is more difficult and costly for Aberthaw to achieve the same level of abatement as other plant.

B3. BREF limits

Annex V of the IED sets the minimum NOx emission limit values, which will apply for Aberthaw from 1/7/20 at the end of the Transitional National Plan (TNP). For plant operating for less than 1500 hours per annum an emission limit value (ELV) of 450 mg/Nm^3 (monthly average) is specified as a five year rolling average. Part 4 of IED Annex V requires that:

- no validated monthly average exceed the ELV;
- no validated daily average exceeds 110% of the ELV;
- 95% of validated hourly averages over the year do not exceed 200% of the ELV.

BAT 20 of the approved LCP BAT Conclusions[8] covers NO_x emissions from coal-fired generation, with Table 10.3 specifying the Associated Emissions Levels (AELs). The levels relevant for Aberthaw as a 1500 hour plant are specified in Footnotes 2 and 7 of Table 10.3:

- Footnote 2 – "*In the case of coal-fired PC boiler plants put into operation no later than 1 July 1987, which are operated <1500 h/yr and for which SCR and/or SNCR is not applicable, the higher end of the range is 340 mg/Nm^3*"
- Footnote 7 – "*In the case of plants put into operation no later than 7 January 2014, the higher end of the range is 200 mg/Nm^3 for plants operated ≥1500 hour and 220 mg/Nm^3 for plants operated < 1500 h/yr.*"

Therefore, if interpreted literally the applicable BREF limit depends on whether SCR/SNCR is used for abatement. This assessment has evaluated all potential abatement measures, including those that are not able to meet the BREF limits.

[8] http://ec.europa.eu/transparency/regcomitology/index.cfm?do=search.documentdetail&Dos_ID=14177&DS_ID=50159&Version=1

B4. Methodology & Assumptions

B4.1 Scope of analysis

The analysis has assumed a baseline of 450 mg/Nm^3 as required by the IED for plant operating for less than 1500 hours per annum, assumed to be achieved from the current conversion of the plant to allow high volatile coal and subsequent optimisation, in line with the main report proposal. All potential abatement options to reduce NOx have been assessed. Where options are able to go beyond the BREF limits then the benefits of the full abatement potential has been assessed, rather than just that to the BREF limits. Plant lifetime has been treated as a sensitivity in the range 2025 to 2028, to align with the Government's consultation or the technical lifetime of the plant.

B4.2 Abatement Options

The abatement options described in Section 5 of the main report have been used for this additional assessment for the post BREF period. The assumptions made for these options are summarised in Table B4.2 below.

Abatement Option	Abatement Range **mg/Nm^3**	NOx assumed for CBA	Capex £m/yr	Opex £m/yr	Basis / Comment
Baseline (HiVM and Windbox) IED compliance	-	450 mg/Nm^3 3687 t/yr	-	-	Achieved from conversion to allow use of high volatile coal and subsequent optimisation
LNBo Units 7 & 8	305 – 370	340 mg / Nm^3 2786 t/yr	30.4	0	Based on Unit 9 costs
Sensitivity assessment Light LNBo **Units 7 & 8**	362 – 451	407 mg / Nm^3 3335 t/yr	25.2	0.14	Not a proven option but undertaken as a sensitivity.
Sensitivity assessment OFA only **Units 7 & 8**	402 – 491	447 mg/Nm^3 3662 t/yr	18.9	0.28	Not a proven option but undertaken as a sensitivity
SCR Units 7 & 8	135 – 186	150 mg/Nm^3 1229 t/yr	108	1.16	Installation on two units is minimum which would allow the 220 mg/Nm^3 limit to be achieved as a stack average. High abatement assumed (beyond BREF limit) to ensure maximum possible benefit is captured in the analysis.
SNCR Units 7,8 & 9	283 – 408	336 mg/Nm^3 2753 t/yr	54.6	1.5	Average costs from TFTEI used. This level of abatement highly unlikely to be achievable at Aberthaw.
Sensitivity assessment SNCR **TFTEI lower capex** Units 7,8 & 9	283 – 408	336 mg/Nm^3 2753 t/yr	39	1.5	Low end of TFTEI cost range assumed. This level of abatement highly unlikely to be achievable at Aberthaw.
Hybrid SCR Units 7 & 8	202 - 270	223 mg/Nm^3 1827 t/yr	83.1	1.3	Installation on two units would allow the limit of 220 mg/Nm^3 to be achieved as a stack average.

Table B4.2. Summary of costs and performance assumptions used in the cost benefit analysis for the plant operating at full load for 1500 hours per annum.

B4.3 Approach used to evaluate costs and benefits

The IED has a general requirement to apply BAT, taking into account effectiveness, technical viability and economic feasibility as well as environmental benefits. The main part of this report has assessed BAT against these ongoing requirements. Additionally the IED specifies particular requirements relating to the implementation of BAT conclusions which have been adopted via the Article 75 procedure. Specific methodologies have been developed by the UK Regulators to assist in the assessment of the proportionality of abatement costs and benefits against these particular requirements. A cost-benefit assessment tool[9] is available for this purpose and this has been used to assess abatement options for the post BREF period. Table B4.3 below sets out the assumptions used in conducting the assessment.

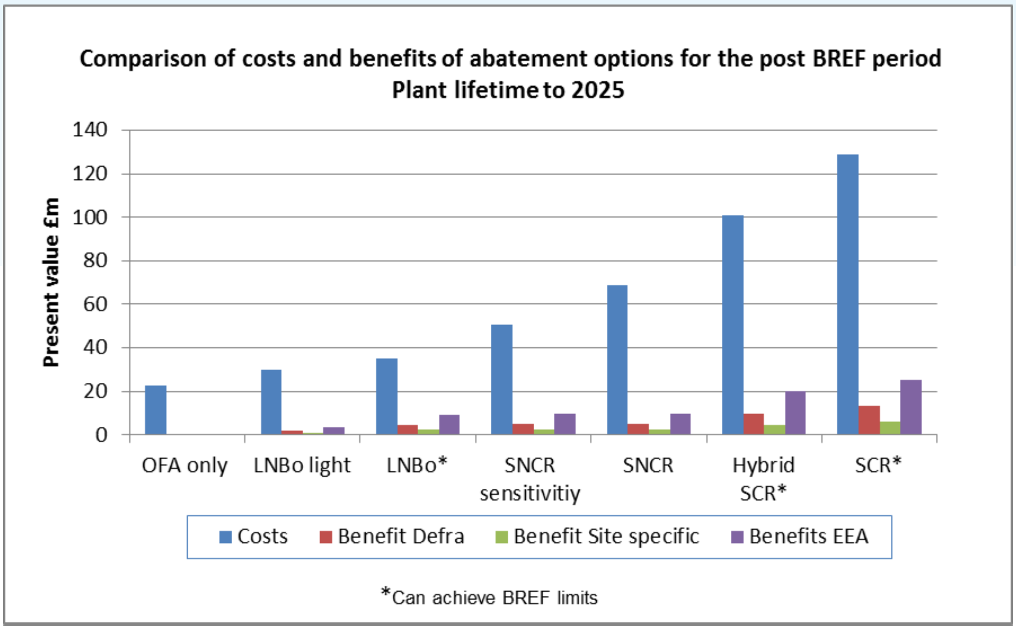
Parameter	Value	Justification
Weighted average Cost of Capital (WACC)	-	Commercially confidential. Value and justification can be provided to NRW on request.
Base year for assessment	2017	As per IED CBA tool guidance.
Installation year	2021	It is assumed that any abatement costs are incurred from the start of 2021. For the purposes of the assessment it has been assumed that the abatement is effective from the middle of 2021. i.e. Prior to mid 2021 emissions are assumed to be IED compliant (450 mg/Nm3), years after 2021 have emissions determined by the assessed abatement option and 2021 has the average of the two. These are simplistic assumptions which take no account of installation time but are sufficient for the purposes of the assessment.
Closure date		As outlined in Section 2 of this report Aberthaw's lifetime is very uncertain. Therefore, this has been treated as a variable in the range 2025 to 2028. 2025 aligns with the Government's consultation on coal closure but 2028 reflects the technical lifetime of the plant and ensures that the assessment is robust against any requirement to operate beyond this date for security of supply purposes.
Capital costs		Following the embedded guidance Year 0 capital costs have been entered into the year in which they fall, on the assumption that the embedded price base corrections and discounting approach assumes that this is the case.
Operating costs		Although the tool allows for individual cost components (operating costs, waste output, energy consumptions) to be considered, conservatively, only the purely operational costs have been considered (as one overall cost).
Environmental Impacts		Only NOx emissions have been considered (as these are expected to dominate the assessment). The tool allows for the monetisation of emissions of air pollutants and (process or fuel-related) Greenhouse Gases. This is a conservative assumption as the inclusion of other components (e.g. CO_2 associated with energy costs or residual ammonia slippage) is expected to decrease the benefits associated with the abatement option under assessement.
Annual NOx emissions for baseline scenario	3687 t/yr	Calculated assuming 1605 MW operates for 1500 hours per year with emission concentrations of 450 mg/Nm^3. The calculations have assumed a station efficiency of 38.5% and a flue gas flow factor of 364 Nm^3/GJ.
Annual NOx emissions for abated scenarios		Scaled from baseline in proportion to abated emission concentration.
Damage costs for NOx	£1263/t £2432/t £600/t	Defra (2015) central value for Energy Supply Industry (ESI)[10] Sensitivity - EEA value as given in the IED cost-benefit assessment tool. Sensitivity – Site specific damage costs derived as set out in Appendix BA1.

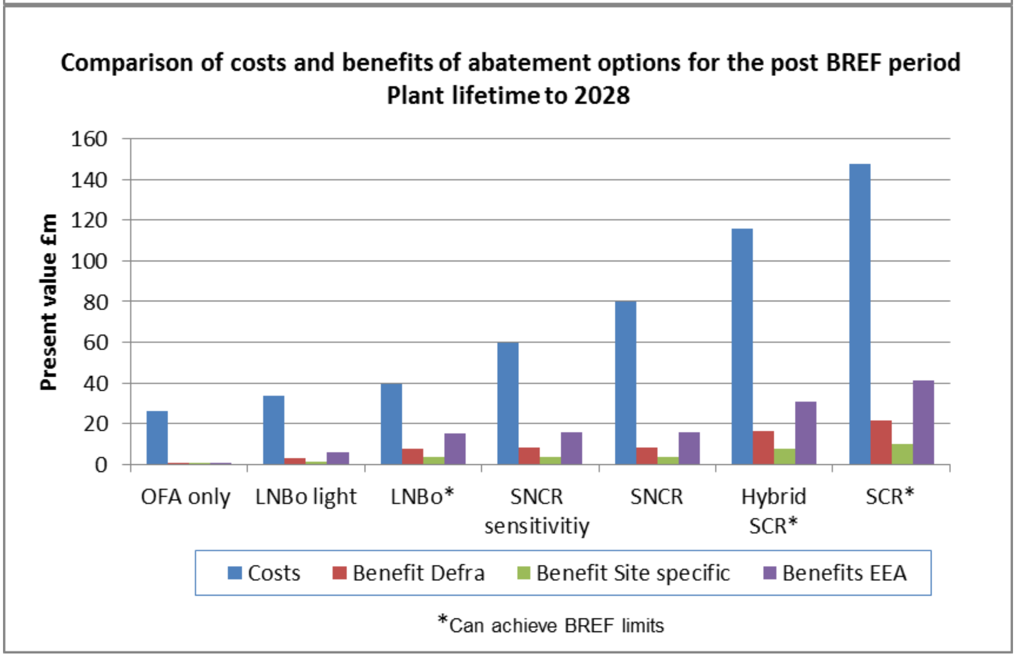
Table B4.3. Assumptions used in the IED cost benefit assessment tool to assess abatement at Aberthaw.

[9] https://www.gov.uk/government/publications/industrial-emissions-directive-derogation-cost-benefit-analysis-tool
[10] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/460398/air-quality-econanalysis-damagecost.pdf

B5 Results and discussion of cost benefit assessment

The results for the cost benefit asessment for the abatement options are detailed in Appendix BA2 and are shown graphically in Figures B5.1 and B5.2 below.

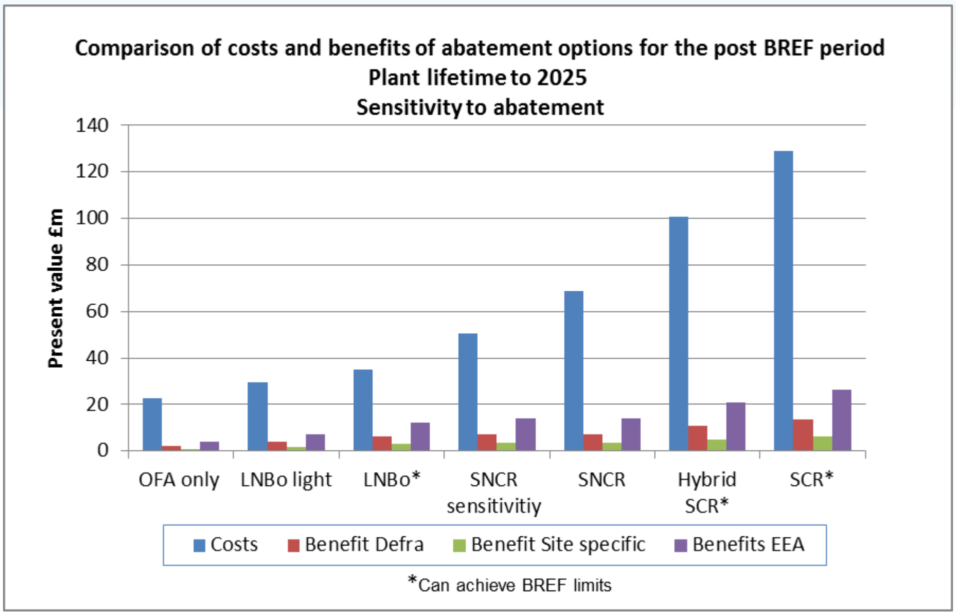


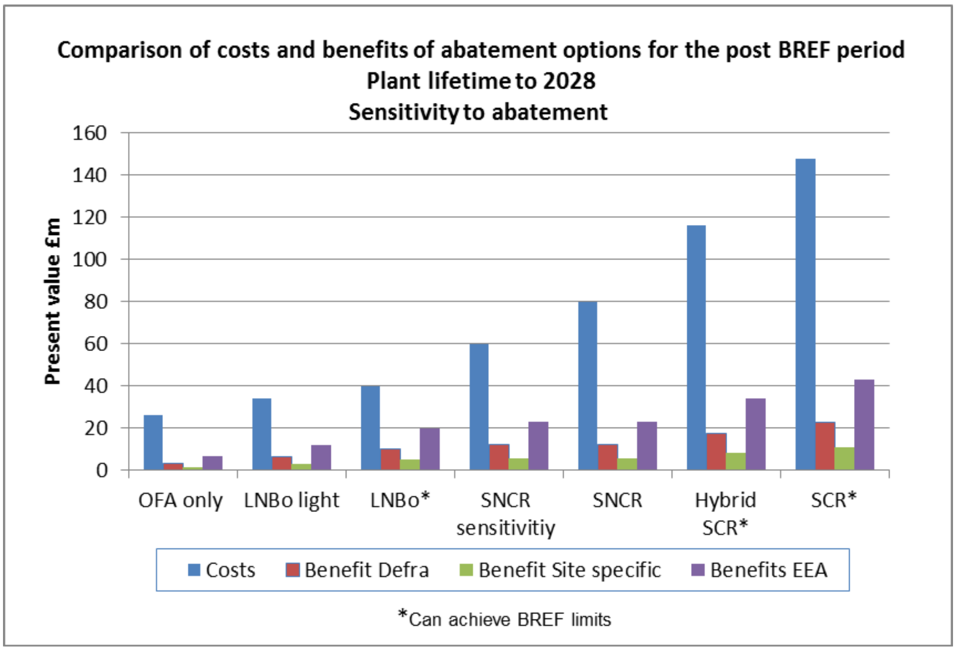


Figures B5.1 and B5.2. Graph showing costs and benefits of post BREF abatement options.

The assessment demonstrates that for all the abatement options the monetised benefits are much lower than the costs for all the lifetimes investigated and for all the considered damage costs. For a closure date aligned with Government coal phase-out consultation, costs exceed benefits by a factor of 7 or greater using the current Defra damage cost[10] and a factor of 15 or greater using the site specific damage cost. Using the EEA damage cost as a sensitivity, the costs still exceed the benefits by a factor of 3.7 or greater for 2025 closure. Even for the latest closure date investigated, the costs still outweigh the benefits by a significant amount (a factor of 5 or more using the Defra damage costs, 10 or more using the site specific costs and 2.6 or more using the EEA value).

For completeness a further sensitivity has been undertaken to assess the impact of using the lowest theoretical NO_x concentration which could be achieved from each of the abatement options. It should be stressed that this is not considered to be necessarily representative of achievable and sustainable abatement in practice – for example the low end of the abatement range from further deployment of Low NOx Boilers would require use of particular coals and operating conditions. For SNCR, as noted in Section 5.3, only low levels of abatement are expected to be achievable at Aberthaw because of the particular plant configuration and future operational patterns. The results of this assessment are shown in Figures B5.3 and B5.4 below with numeric values given in Appendix BA2.





Figures B5.3 & B5.4. Sensitivity of costs and benefits to abatement assumptions.

This further sensitivity test does not change the conclusions of the analysis.

It should also be noted that the cost benefit assessment has been performed using very pessimistic assumptions so the actual disproportionality is likely to be much higher than that presented in this analysis.

In particular:

- Aberthaw has been assumed to generate at the maximum possible as a <1500 hour plant, whereas in practice generation may be significantly lower than this.
- No account has been taken of installation time for any of the technologies. The installation times are very significant for many of the options – for example Low NOx Boiler Technology took 7 months to install on Unit 9.
- For SNCR the achievable abatement is likely to be much lower than that assumed, due to the technical difficulties with targetting the temperature window associated with Aberthaw's unusual design and the intermittent nature of future generation. Additionally the disbenefits of ammonia slip have not been considered.

B6. Conclusions

The costs and benefits of all potential NOx abatement options have been assessed assuming Aberthaw operates for 1500 hours per year following implementation of BREF. Sensitivities to abatement potential, capital costs, damage costs and closure date have been explored. The analysis has demonstrated that the abatement costs are vastly disproporortionate to the environmental benefits and this conclusion is robust even when extreme assumptions are made for sensitivity purposes.

Appendix BA1. Derivation of site specific NOx damage cost

The '*site-specific damage costs for implementation of the Industrial Emissions Directive*'[11] provides a framework for the derivation of site-specific damage costs. The assessment framework relies on two key steps:

- the use of an air quality dispersion model (approved for regulatory use) to estimate ground level annual mean concentrations for the pollutants of interest;
- the use of a spreadsheet tool to estimate, combining the modelled ambient concentration footprints with the provided gridded population data, the damage costs.

This Appendix sets out the application of this methodology to derive a site specific damage cost for Aberthaw Power Station.

Dispersion modelling

The annual averaged ground level NO_2 concentration footprint, required in the assessment of the site-specific damage costs, has been modelled using the ADMS (version 5.2) dispersion model. ADMS is a well-established dispersion model (approved for regulatory use), which has undergone several validation studies[12] and has been used extensively for industrial power stations. The main input parameters used in the simulation are summarized below:

Input Parameter	Input Value
Stack Coordinates (Ordnance Survey National Grid reference system)	Easting=302400 ; Northing=166300
Exhaust gas release height (m)	152
Effective internal stack diameter (m)	11.88
Exit temperature (°C)	50
Volume flux at full load per stack (Am^3/s)	1817
NOx emission rate (g/s, NO_2-equivalent)	684g/s (of which 1.6% is NO_2)

To model the total station contribution to NO_2 concentrations, ADMS offers a NOx chemistry module which takes account of background levels of NOx, NO_2 and ozone. For this specific modelling, the NOx chemistry module was run using 2006 measured hourly background O_3 air concentration data from the UK National Air Quality Archive for Yarner Wood in south Devon[13] (no background NO and NO_2 measurements were included, and the model runs used 2006 hourly meteorology data from the Met Office monitoring site at St. Athan).

Ground level concentrations were calculated across 250m grid squares covering a spatial domain of 50x50km, centred on the Power Plant[14] (and positioned consistently with the provided gridded population data). The selected domain is anticipated to capture the overall footprint of the released NOx (and to possibly overestimate the actual impacts as, at large distances from the emission source, concentrations tend to be limited by longer-term depletion and loss mechanisms – such as oxidation to nitrate, dry and wet deposition – that are not considered in the ADMS simulation).

The resulting footprint is shown below, together with the population map[15] used in the site-specific assessment.

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[11] Report ED 59323809 (Issue Number 1 of 15/03/2017) for ShARE Group (Natural Resources Wales, Scottish Environment Protection Agency, Department of the Environment for Northern Ireland, the Environment Agency). Draft methodology provided by NRW for sensitivity purposes.

[12] see for example: *Estimated power-station contributions to ground-level concentrations of NO_2* - JEP report ENV/269/2008 by A. Webb.

[13] as, under the model assumptions, most of the damage costs tend to originate at relatively large distances from the emitting stack (>15km, see Figure 2), the use of the ADMS ozone chemistry model results in (slightly) higher site-specific damage costs than those estimated under the usual convention of annual mean NO_2 process impacts equivalent to 70% of the modelled NOx long-term average concentrations. The use of the ADMS chemistry module represents therefore, in this specific case, a conservative assumption.

[14] it is worth noting that the domain is larger than the one usually considered in air quality assessments, as well as the one (5x5km) used in the case study example provided in the guidance (to assess site-specific damage costs for emissions from a 101m stack height – see Section 4 in the '*site-specific damage costs for implementation of the Industrial Emissions Directive*')

[15] as provided at: https://uk-air.defra.gov.uk/data/density

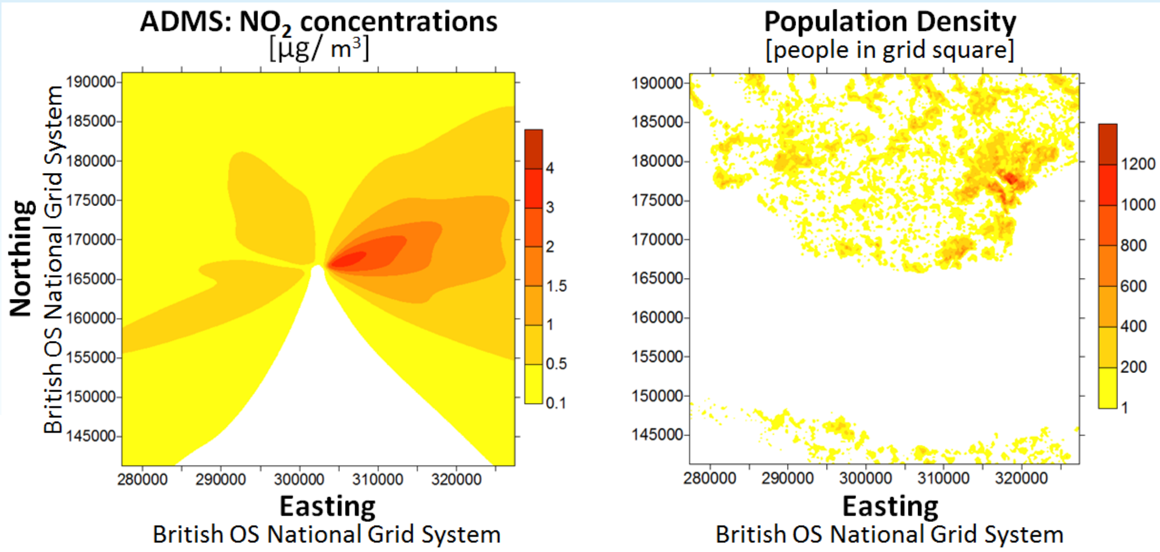

Figure 1: NO_2 concentrations and population density used in the assessment of Aberthaw site-specific damage costs

Site-specific Damage Costs

The provided framework for producing site-specific damage costs is consistent with the guidance for air quality appraisal and the most recent update of the IGCB damage costs. More specifically, the estimated NOx damage cost is expressed as the sum of two contributions, to reflect:

- the *'primary'* impact pathways, directly associated with exposure to NO_2; and
- the *'secondary'* impact pathways: associated with exposure to perturbations in the background concentrations of secondary particulate and ozone (driven by the emitted NOx)[16].

The focal aim of the provided tool is to allow a site-specific assessment of the 'primary' contribution, as the (additional) 'secondary' contribution consists of a pre-specified value, which has been derived at national scale, and is therefore independent of the characteristics of the site-dependent emissions[17].

The resulting total damage cost (expressed in $£_{2015}$/tNOx, and calculated using the provided Excel tool) is summarized in the chart below, which shows its dependence on the size of the spatial domain (squared domain, centred on Aberthaw) considered in its assessment.

[16] as a result of chemical processes in the atmosphere that occur over a long time-frame and once the primary emitted pollutants have achieved a much wider level of dispersion

[17] for emissions from Power Stations, this consists of a rather conservative assumption. As demonstrated in several international studies, even for 'secondary' impacts, emissions from 'high stacks' (e.g. *SNAP 01: Combustion in energy and transformation industries*) are characterized by damage costs (£/tNOx) that are significantly lower than the national averaged ones: see, e.g., the results of the EURODELTA project (coordinated by the European Commission Joint Research Centre, JRC, at Ispra) and reference herein: https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/eurodelta-evaluation-sectoral-approach-integrated-assessment-modeling-second-report

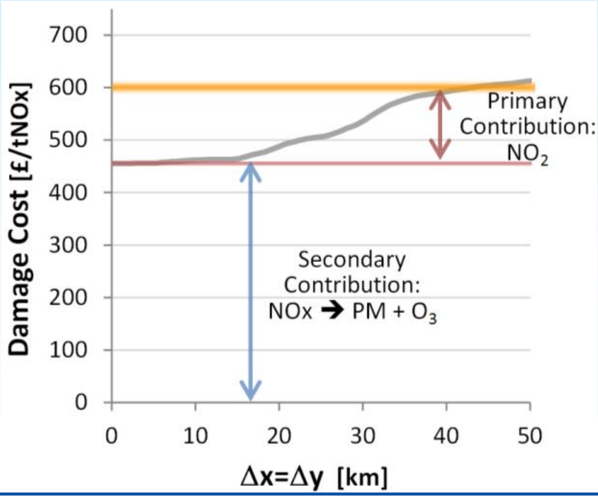

Figure 2: dependence of the resulting site-specific damage cost calculated using the provided Excel tool) on the size of the domain used in its assessment. The horizontal orange line (at 600£/tNOx) refers to the site-specific value proposed for the BAT assessment.

From the chart, one can see that the total damage cost tends to be dominated by the (site independent) *'secondary'* impact pathways (for which a national value of 456$£_{2015}$/tNOx is assumed within the provided tool). The inclusion of *'primary'* impact pathways further increases the total damage cost, from 456 to ~600$£_{2015}$/tNOx. The upper value of 600$£_{2015}$/tNOx is believed to represent a reasonable (conservative) estimation of the site-specific damage cost as, as already mentioned:

- the estimated *'primary'* contribution (exposure to the primary NO_2) does not account for depletion and loss mechanisms (e.g. oxidation to nitrate, dry and wet deposition) that would reduce the exposure to NO_2 at large distances from the emission source;
- under the provided approach, a national average is used to quantify the *'secondary'* contribution, while literature agrees that the secondary impacts of NOx emitted by the Power Sector tend to be lower than the national average.

Finally, it is worth noting that the site-specific value of 600$£_{2015}$/tNOx, proposed to be used in the BAT assessment, is fully consistent with the 'reference' damage cost (for selected sectors) reported in the provided excel tool for the category representative of Aberthaw emissions:

Emission Category	Provided Damage Cost [$£_{2015/tNOx}$]
Category 7: *Stack height > 100 m, population density ≤ 250 people per km^2*	603
Category 8: *Stack height > 100 m, population density >25, ≤ 1000 people per km^2*	664

(as the population density, on a 50x50km domain centred on Aberthaw, is ~235 people per km^2).

Appendix BA2. Costs and benefits of BREF abatement

Table BA2.1 Comparison of costs and benefits of abatement options for the post BREF implementation perod using the expected abatement performance.

Abatement	Plant lifetime after abatement installed Yrs (date)	Present Values of Costs & Benefits (£m)			
		Costs	Benefits derived from damage costs		
			Defra	EEA	Site specific
Low NOx Boiler Technology Units 7 & 8	4.5 (~end 2025)	35.2	4.9	9.4	2.3
	5.5 (~end 2026)	36.7	6.0	11.6	2.9
	6.5 (~end 2027)	38.2	7.0	13.5	3.3
	7.5 (~end 2028)	39.7	8.0	15.4	3.8
Sensitivity assessment Light Low NOx Boiler Technology Units 7 & 8	4.5 (~end 2025)	29.7	1.9	3.7	0.9
	5.5 (~end 2026)	31.1	2.3	4.4	1.1
	6.5 (~end 2027)	32.4	2.7	5.2	1.3
	7.5 (~end 2028)	33.7	3.1	6.0	1.5
Sensitivity assessment OFA only Units 7 & 8	4.5 (~end 2025)	22.9	0.1	0.2	0.1
	5.5 (~end 2026)	24.1	0.2	0.4	0.1
	6.5 (~end 2027)	25.2	0.2	0.4	0.1
	7.5 (~end 2028)	26.3	0.2	0.4	0.1
SCR Units 7 & 8	4.5 (~end 2025)	129.1	13.5	26.0	6.4
	5.5 (~end 2026)	135.5	16.3	31.4	7.7
	6.5 (~end 2027)	141.7	19.2	37.0	9.1
	7.5 (~end 2028)	147.7	22.0	42.4	10.5
SNCR Costs and abatement from TFTEI Units 7,8 & 9	4.5 (~end 2025)	68.6	5.1	9.8	2.4
	5.5 (~end 2026)	72.5	6.2	11.9	2.9
	6.5 (~end 2027)	76.3	7.3	14.1	3.5
	7.5 (~end 2028)	79.9	8.3	16.0	3.9
Sensitivity assessment SNCR TFTEI lower capex Units 7,8 & 9	4.5 (~end 2025)	50.6	5.1	9.8	2.4
	5.5 (~end 2026)	53.7	6.2	11.9	2.9
	6.5 (~end 2027)	56.7	7.3	14.1	3.5
	7.5 (~end 2028)	59.6	8.3	16.0	3.9
Hybrid SCR Units 7 & 8	4.5 (~end 2025)	100.8	10.2	19.6	4.8
	5.5 (~end 2026)	106.1	12.4	23.9	5.9
	6.5 (~end 2027)	111.1	14.5	27.9	6.9
	7.5 (~end 2028)	116.0	16.6	32.0	7.9

Table BA2.2 Comparison of costs and benefits of abatement options for the post BREF implementation perod using the maximum feasible NOx abatement performance. Note this has been performed as a sensitivity test and it is not considered that these levels of performance are necessarily achievable or sustainable.

Abatement	Plant lifetime after abatement installed Yrs (date)	Present Values of Costs & Benefits (£m)			
		Costs	Benefits derived from damage costs		
			Defra	EEA	Site specific
Low NOx Boiler Technology Units 7 & 8	4.5 (~end 2025)	35.2	6.5	12.5	3.1
	5.5 (~end 2026)	36.7	7.9	15.2	3.8
	6.5 (~end 2027)	38.2	9.3	17.9	4.4
	7.5 (~end 2028)	39.7	10.6	20.4	5.0
Sensitivity assessment Light Low NOx Boiler Technology Units 7 & 8	4.5 (~end 2025)	29.7	3.9	7.5	1.9
	5.5 (~end 2026)	31.1	4.8	9.2	2.3
	6.5 (~end 2027)	32.4	5.6	10.8	2.7
	7.5 (~end 2028)	33.7	6.4	12.3	3.0
Sensitivity assessment OFA only Units 7 & 8	4.5 (~end 2025)	22.9	2.2	4.2	1.0
	5.5 (~end 2026)	24.1	2.6	5.0	1.2
	6.5 (~end 2027)	25.2	3.1	6.0	1.5
	7.5 (~end 2028)	26.3	3.5	6.7	1.7
SCR Units 7 & 8	4.5 (~end 2025)	129.1	14.1	27.2	6.7
	5.5 (~end 2026)	135.5	17.1	32.9	8.1
	6.5 (~end 2027)	141.7	20.1	38.7	9.5
	7.5 (~end 2028)	147.7	23.1	44.5	11.0
SNCR Costs and abatement from TFTEI Units 7,8 & 9	4.5 (~end 2025)	68.6	7.5	14.4	3.6
	5.5 (~end 2026)	72.5	9.1	17.5	4.3
	6.5 (~end 2027)	76.3	10.7	20.6	5.1
	7.5 (~end 2028)	79.9	12.2	23.5	5.8
Sensitivity assessment SNCR TFTEI lower capex Units 7,8 & 9	4.5 (~end 2025)	50.6	7.5	14.4	3.6
	5.5 (~end 2026)	53.7	9.1	17.5	4.3
	6.5 (~end 2027)	56.7	10.7	20.6	5.1
	7.5 (~end 2028)	59.6	12.2	23.5	5.8
Hybrid SCR Units 7 & 8	4.5 (~end 2025)	100.8	11.1	21.4	5.3
	5.5 (~end 2026)	106.1	13.5	26.0	6.4
	6.5 (~end 2027)	111.1	15.8	30.4	7.5
	7.5 (~end 2028)	116.0	18.1	34.9	8.6

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