Aberthaw – Schedule 5 responses

Location: Aberthaw Power Station

Permit Number: EPR/RP3133LD

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The energy to lead

Aberthaw – Schedule 5 responses

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1 Introduction

This document sets out responses to a request by Natural Resources Wales (Notice for further information, dated 14th May 2015) to support the application to vary the existing Environmental Permit (EPR/RP3133LD) for the site to upgrade the boilers to reduce NO_x emissions to air.

Although RWE indicated in the forms accompanying the variation application that we would like a consolidated permit we understand this could delay the issue of the variation and therefore would **accept an unconsolidated version.**

2 Responses to questions

2.1 Question 1

Assessment needs to be made to demonstrate quantifiably how the proposed low NO_x boilers will preferentially affect air emissions. Please provide an updated Air Quality impact assessment using extrapolated data from existing modelling and local monitoring data that considers likely future load factors.

Response

Please find in Appendix A an updated Air Quality impact assessment, this is a full assessment rather than using extrapolated data. Below is a summary of the results:-

For the purposes of assessing the reduction in impacts, three emissions scenarios were modelled. The impacts will depend on both the emission concentration and the load factor and a wide range of combinations are possible depending on the timing of the modification and future load factors. Therefore, the scenarios were chosen to represent the possible **range** of impacts over the next few years against a pre-modification baseline scenario. The scenarios modelled were:

Scenario 0: This scenario is representative of the high end of recent generation by Aberthaw Power Station, before the proposed low NO_X boiler modifications.

Scenario 1: This scenario corresponds to the expected operation immediately after the low NO_X boiler modification on one of the three generating units, with a load factor at the high end of expectations.

Scenario 2: This scenario corresponds to the possible future operation after the low NO_X boiler modification on all three generating units and with the station operating at a low load factor.

The modelling results demonstrate that the proposed low NO_X boiler modifications will result in reductions in the impact of the power station on local air quality and deposition.

For the assessment of impacts on human health, it was found that modelled NO_2 concentrations are compliant with both short-term and long-term NAQOs for all three scenarios. The proposed low NO_X boiler modifications will result in reductions in the station's contribution to the short-term impact by between 3% and 14% and long-term impacts by between 7% and 85%.

2.2 Question 2

In considering air quality impacts, consideration should be given towards quantifying any impact towards European Designated sites (and local). Please demonstrate with reference to critical loads for European Sites how the proposed changes will provide improvements against the critical loads.

Response

The detail on impacts on European sites is also included in the report in Appendix A, the same scenarios as above were chosen. Below is a summary of the results:-

For the assessment of impacts on nature conservation sites, it was found that the modelled annual mean NO_X concentrations are below the critical level for all sites for all three scenarios. The proposed low NO_X boiler modifications will result in reductions in the station's contribution to the impact by between 14% and 90%.

Considering the reduction in the number of sites selected by significance screening for the maximum daily mean NO_X concentrations (i.e. selecting sites for which the modelled concentration is above the critical level and the station's contribution is above the 10% screening threshold), the proposed low NO_X boiler modifications will result in between one less SINC site being selected to no sites being selected. The station's contribution to the concentration will reduce by between 14% and 57%.

Considering the reduction in the number of sites selected by significance screening for the annual nutrient nitrogen deposition (i.e. selecting sites for which the modelled deposition is above the critical load and the station's contribution is above the 1% screening threshold), the proposed low NO_X boiler modifications will result in between one less site (1 SINC site) and seven less sites (4 SSSI sites and 3 SINC sites) being selected. The station's contribution to the deposition will reduce by between 10% and 88%.

For annual acid deposition, it was found that the modelled deposition is above the critical load and the station's contribution is above the 1% screening threshold at only one site. The modelled total deposition for this site is only just above the critical load (=101.0% of the critical load). The modelling results found that the proposed low NO_X boiler modifications may result in the total deposition for this site moving below the critical load, depending on the reduction in NO_X emissions achieved and future load factors. The station's contribution to the deposition will reduce by between 2% and 79%.

2.3 Question 3

Section 5.4 of the supporting document submitted as part of the application does not consider the increase in carbon in ash levels in sufficient detail. Demonstration is needed that the projected increase in carbon in ash from current 8-10% levels to 13-20% will not significantly impact the performance of the Electrostatic Precipitators and if there will be any consequential impact upon seawater discharges from the Flue Gas Desulphurisation (e.g. mercury emissions), performance of the ash reprocessing facility or dust releases to air.

Response

This response summarises the position for Carbon in Ash (CinA) at Aberthaw before and after Low NO_x Boiler (LNBo) implementation. This is important for consideration of impact on dust emissions. The overall conclusion is that CinA levels are not expected to increase above critical level (> 20% CinA) where there is a risk of reduced Electrostatic Precipitators (ESP) performance with consequent impact on increased dust emission limits. Keeping below the critical level can be done because of improvements to flame ignition and Pulverised Fuel (PF) distribution (as part of LNBo implementation) which should result in an improvement in combustion to offset the effect of delay in combustion from air staging required for NO_x control. Therefore there is also unlikely to be adverse consequential impact upon: seawater discharges from the FGD (e.g. mercury emissions), performance of the ash reprocessing facility, disposal of PFA to the quarry ash disposal site or dust releases to air.

Aberthaw's current day-to-day carbon in ash is approximately 11-15%, see Figures 1 and 2 below, (not the 8-10% indicated by NRW which reflects the best / guarantee performance from the dynamic classifiers for the guarantee fuel). The key difference between the figures is that Aberthaw utilises the benefit of dynamic classifiers to trim NO_x with excess air control in combination with existing NO_x techniques e.g. Thermal Input Biasing (TIB). There is also plant degradation between overhauls and fuel quality issues to consider in day-to-day results.

The LNBo will increase staging of air for combustion, reducing NO_x emissions from the modified boiler unit but with potential to increase carbon in ash. The LNBo supplier has offered both **expected** and **guaranteed** figures for CinA and both are within the range of normal CinA operating levels. The supplier considered the impact of all of the LNBo plant and operational changes and have concluded that several factors will offset the air staging adverse impact on CinA, these include:

- Mill PF Quality Improvements – increased mill ball charge and higher classifier speed
- PF Distribution Improvements – plant and operational changes at the classifier outlet, redesigned PF leg orifice plates and burner inlet riffles. Balanced thermal input between mills.
- New Foster-Wheeler Pre-Heat Burner – improved ignition and burner aerodynamics
- New Foster-Wheeler Overfire System – increased turbulence and burnout in the upper furnace

Performance Guarantees for CinA from the supplier are 13-15% for Unit 9. They have also provided Expected CinA Performance figures of 10 – 12% depending on coals fired. These levels would be achieved from the return to service of the unit but 'normal' increased in CinA can be expected between outages (e.g. due to changes in plant condition).

Therefore CinA guarantees are likely to be similar to current plant performance once the optimisation and tuning periods are complete, i.e. post plant handover. Normal day-to-day variation in carbon-in-ash can be expected due to: operation of the unit, fuel quality changes and changes in environmental ambient conditions affecting firing-rates / heat-rate of the unit.

For reference purpose: prior to installation of dynamic classifiers, the carbon in ash levels were typically 15-17% (TECH/JJB/1593/11 RWE npower Aberthaw Power Station – Unit 7 Dynamic Classifier Retrofit Evaluation Report for the Environment Agency).

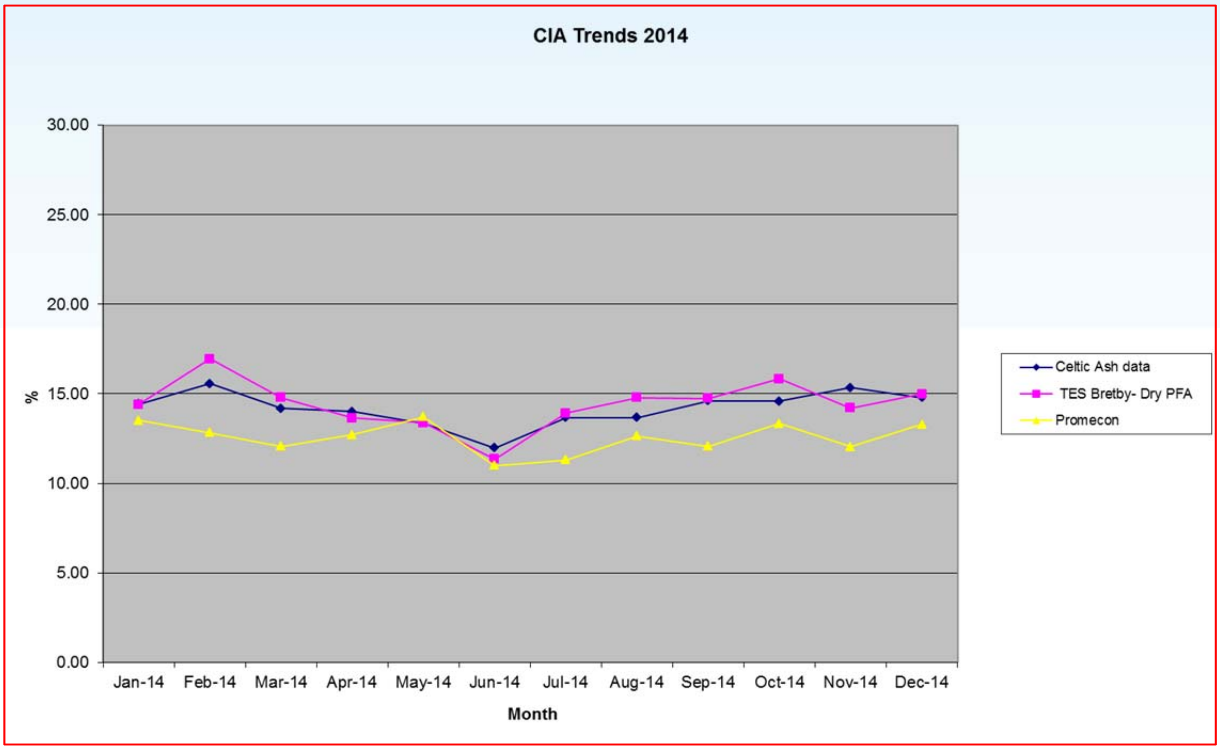


Figure 1: Aberthaw Carbon in Ash Measurements 2014

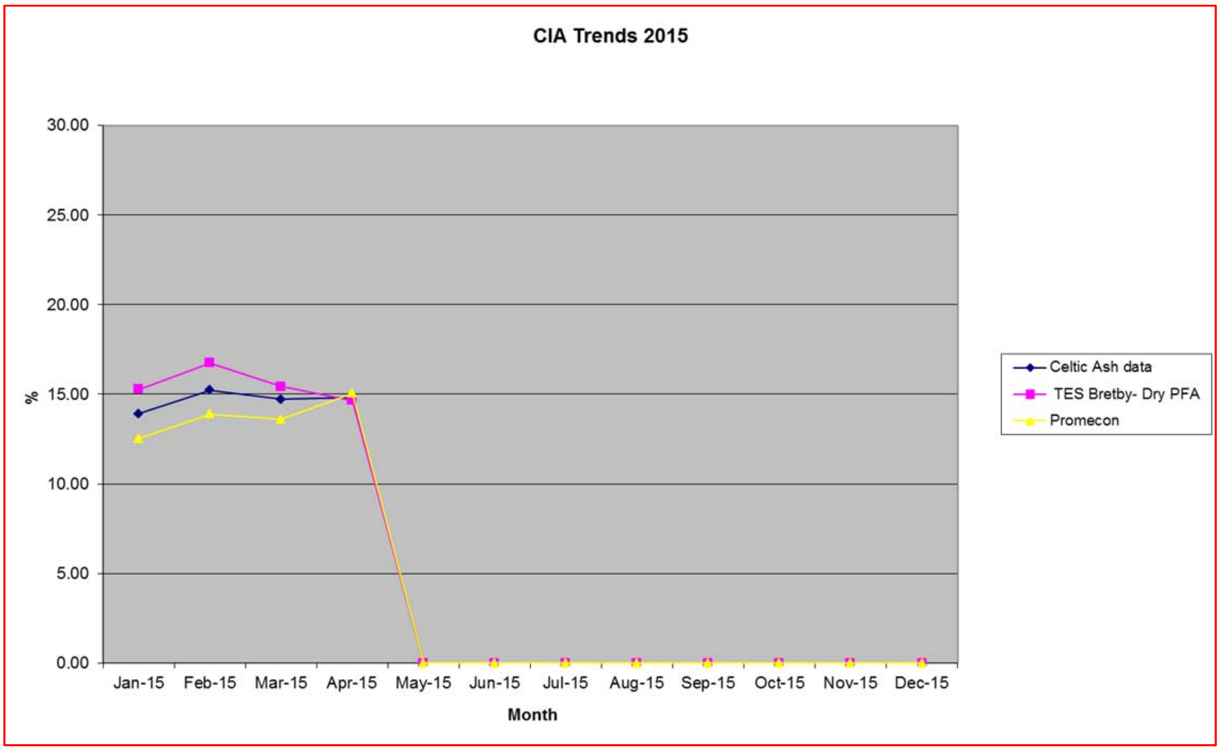


Figure 2: Aberthaw Carbon in Ash Measurements 2015

The supplier has offered CinA guarantees which are at or better than current plant performance therefore RWE expects little or no impact on ESP dust removal performance and consequential impact on seawater discharges, performance of the ash reprocessing facility, disposal of PFA to the quarry ash disposal site or dust releases to air.

2.4 Question 4

Section 2 of the submitted documents does not provide information in sufficient detail to consider the performance of similar low NO_x boilers. Please provide technical reports on the performance and commissioning of the low NO_x boilers installed at the Compostilla plant.

Response

RWE have not been able to secure detailed information on Compostilla specifically, we attach (in Appendix B) public domain information on the components of the type of system that will be deployed at Aberthaw. Compostilla is just one of the few plants where these components have been deployed and there are differences between Compostilla and Aberthaw. These include:-

- Differences in coal quality and volatile matter (VM)
- Differences in boiler design (although both are arch fired)
- Differences in mill, classifier type and overfire air design
- Differences in burner operation
- Cyclones were already installed pre LNBo
- Different commercial operation

In summary, some information would be relevant but the performance information would not be a good indicator without the detailed knowledge of the supplier on how to apply their design to Aberthaw.

The attached papers indicate the overall experiences of the supplier. Aberthaw is unique in many regards, indeed plants (arch-fired) designed to burn low volatile are relatively rare plus low NO_x arch-fired low VM plants are even rarer still. Hopefully the attached papers contain enough relevant information to give insight on the Aberthaw LNBo philosophy.

2.5 Question 5

Clarification is required regarding the status of the current permission to install SCR across all three units, the requirement to use thermal input biasing and combustion control. Please provide an updated options appraisal demonstrating what BAT is for NO_x control under the possible future operating regimes..

Response

There are three linked sub-questions within this request. Each is answered in the following sections.

Status of the current permission to install SCR at Aberthaw.

RWE Generation UK operate Aberthaw power station under permit EPR/RP3133LD. The permit was varied in 2012 to allow the operation of Selective Catalytic Reduction (SCR) to reduce emissions of oxides of nitrogen to air, the implementation of activated carbon injection to increase mercury removal from combustion gasses, and an increase in the quantity of ammonia (used in the SCR process) stored on site.

The decision to apply for a permit variation to operate SCR reflected RWE Generation UK's view of the commercial and regulatory environment at that time. While power plant operation is a commercial decision the energy market is influenced by regulation. Market conditions have changed since the decision to apply for a permit to operate SCR. Current assumptions are that under the probable Industrial Emissions Directive (IED) compliance pathway lower load factors than previously assumed, post Transitional National Plan (TNP), are a more likely scenario. At these lower load factors it is no longer considered to be economic to fit SCR at Aberthaw. For the IED compliance option deemed likely for Aberthaw a different (higher) NO_x limit (450mg Nm^{-3}) than was assumed in the SCR options appraisal is applicable. This limit is achievable by the primary combustion measures already installed (see later for details) in combination with the Low NO_x Boiler technology currently proposed for Aberthaw.

As RWE are now not intending to fit SCR, as part of this variation please remove all references within the permit to SCR.

The status of TIB & Combustion Control

TIB is a technique that involves optimising the heat distribution in the furnace by controlling the burner firing pattern. The technique was demonstrated at Aberthaw to be capable of reducing NO_x emissions by around 20% giving an emission concentration of 1200 mg Nm^{-3}. Operating issues included potentially increased carbon in ash; risk of increased dust emissions; some coal restriction and the risk of furnace wall tube failures. TIB was implemented in 2008 and is now in operation on all of Aberthaw's units.

The operation of TIB can be improved by use of a NO_x advisor system. This involves improved instrumentation and control systems designed to achieve the lowest NO_x set-up. The use of this combustion control system has been shown to help to consistently achieve lower NO_x over that obtained by TIB. The operational issues are the same as with TIB. The overall approach and techniques have been developed and proven and this system is now installed on all three units at Aberthaw.

The operation of TIB and combustion control may be further improved by the use of dynamic classifiers. These in effect achieve better control of the size distribution and balance burner to burner for pulverised coal being fed to the burners. Improvements to pulverised fuel size distribution have the combined benefits of reduced carbon in ash, lower dust emissions and reduced NO_x emissions. It is well known that such an improvement to combustion can achieve all three of these simultaneously. However, the interaction between these parameters is complex; for example optimisation to improve NO_x emissions may result in increased carbon in ash, high dust emissions or increased slagging in the boiler and a balance must be found.

All units at Aberthaw are now fitted with dynamic classifiers as well as thermal input biasing and combustion control. The use of these technologies allow the station to comply with the current limit.

Revised NO_x abatement options appraisal

A revised options appraisal has been undertaken for NO_x abatement at Aberthaw power station. The appraisal has used the same methodology for the calculation of costs and benefits as in ENV/505/2012. There are however a number of differences in the assumptions regarding available technologies, unabated NO_x and load factors.

The average annual load factor used in the assessment of 17% reflects a 1500h compliance route post 2020. There is potential for Aberthaw to operate at a higher load factor during the TNP. As a sensitivity study the cost and benefits of abatement have also been assessed assuming a 50% load factor.

A number of technologies considered previously have been implemented at Aberthaw Power Station and are therefore not considered in this options appraisal. These are TIB, combustion control and dynamic classifiers. Technologies considered are Low NO_x Boiler, SCR and Selective Non catalytic Reduction (SNCR). The base NO_x limit assumed for the current assessment is the limit value that applies from 2016 onwards; 1050mg Nm^{-3} and current coal diets.

Assumptions in Options Appraisal

Item	Value	Notes
Baseline NO_x	1050mg Nm^{-3}	Limit applies from 2016
SCR NO_x Reduction for gas treated	90%	As ENV/505/2012
Hot Gas Tap flow	6.5%	As ENV/505/2012
Load Factor	17% *50%*	Assumed to 2032 *As sensitivity*
Average Unit Heat Rate	9359 MJ/MWh	As ENV/505/2012
Power Cost	£40 /MWh	As ENV/505/2012
Coal	£3.4/GJ	As ENV/505/2012
Annual Generation	2390166MWhr	From load factor
End of Life	2032	DECC Energy projections end of non CCS coal
Start year for life calc	2016	As ENV/505/2012
SNCR % reduction	34%	Upper end of 15 to 35% in BREF submission. BREF submission suggested lower end for low load plant & hence an optimistic assumption
LNBo NOx Reduction	57%	Based on achieving 450mg Nm^{-3}
Coal NCV	26MJ/kg	As ENV/505/2012
Coal ash content	15%	As ENV/505/2012
Carbon in Ash With Dynamic Classifiers	13%	Mid Point of current Range
Carbon in Ash With LNBo	11%	Mid point of expected range
PFA fraction	92%	As ENV/505/2012
Energy in carbon	33.83MJ/kg	As ENV/505/2012

Capital costs (CAPEX) assumed in the options appraisal

CAPEX per unit	CAPEX (£m)	Notes
LNBo	12	Per unit
SCR base cost for 3 Units (per unit)	66.7	Per unit
Without hot gas tap (WGT) NPC compared to with hot gas tap treatment (HGT)	-4.6	Difference in cost of not treating hot gas tap (WGT) flow and treating hot gas tap (HGT) flow.
SNCR	14.5	Mid range of BREF costs

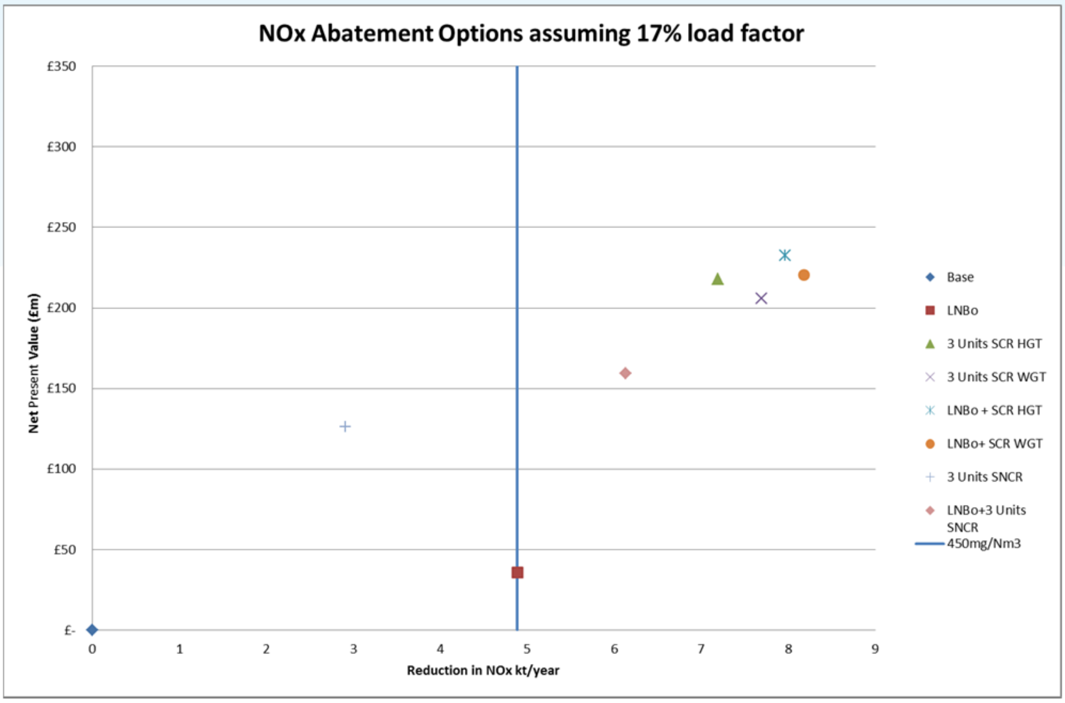
Operation costs assumed in the options appraisal

OPEX per unit	Value	Notes
LNBo	£275,625/year	From 2009 BAT review as previous study which assumed 70% load factor. We now believe this may be pessimistic as the original OPEX costs allowed for potential impacts on the boiler.
SCR	£283,700/year	As previous study Which assumed 70% load factor
SNCR	£1.25/MWhr	BREF submission
Ammonia cost	£370/tonne	Price from GrowHow 2011 (as previous study)

A discount rate of 8.5% has been used to calculate the Net Present Value (NPV) of each option. Where OPEX costs assume a load factor these have been scaled to the load factor appropriate in the current assessment.

In addition to the use of LNBo, SCR and SNCR on all three Aberthaw units the costs and abatement achieved with SCR and SNCR fitted with LNBo have been calculated using the listed assumptions.

Figure 3: Cost and benefit (abatement) for a number of abatement options at Aberthaw power station assuming 17% Load Factor to 2032



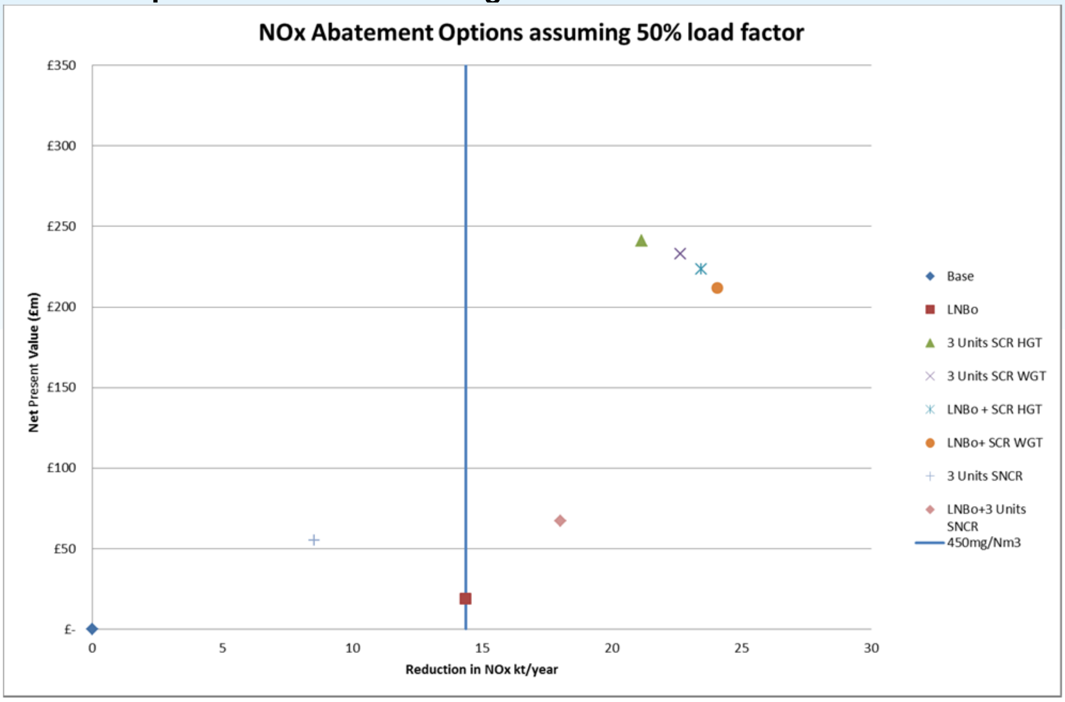
As can been seen for the results plotted in Figure 3 above the use of LNBo provides the lowest cost option of achieving a stack gas NO_x concentration of 450mg Nm^{-3}. SNCR alone is not capable of reducing stack gas concentrations to the required level. The NPV cost of SNCR is also greater than that of LNBo.

The use of SCR, both with and without LNBo, offers abatement below 450mg Nm^{-3} but at a significantly higher NPV than for the LNBo technology alone (£200 to 217.6 million compared to £28.4million).

The use of SNCR with LNBo offers abatement below 450mg Nm^{-3} with a reduced NPV compared to the options that include SCR. However compared to LNBo alone the use of LNBo plus SNCR is more expensive (£70.8million compared to £28.4 million).

A sensitivity study has been undertaken assuming that Aberthaw's load factor was 50% to 2032. This is somewhat unrealistic as while greater than 17% load factors would be possible when operating within the TNP such high load factors would not be possible post TNP without abatement beyond 450mg Nm^{-3}. The NPV cost and NO_x reduction per year for the range of abatement options are plotted in Figure 4 below:

Figure 4: Cost and benefit (abatement) for a number of abatement options at Aberthaw power station assuming 50% Load Factor to 2032



An increase in load factor to 50% does not change the overall conclusions of the cost benefit analysis. The relative values of the cost benefit data for a 50% load factor as plotted in Figure 4 above are similar to those for the 17% load factor case plotted as Figure 3. For both cases LNBo provides the least expensive abatement option. Also for both cases SNCR alone is expensive, relative to LNBo, and does not achieve the required 450mg Nm^{-3}. The use of SCR and SNCR plus LNBo provides abatement beyond 450mg Nm^{-3} but at a significantly increased cost. Compared to the 17% load factor case the SNCR and SCR options increase in cost because of operational costs that increase with increasing load factor. The costs of SNCR options increase proportionally more than the SCR cost because operational costs are proportionally a greater component of the overall cost for that technology.

In conclusion for the life and load factor currently expected the use of LNBo technology provides the most cost effective means of providing NO_x abatement to required limits and should be considered as BAT at Aberthaw. This conclusion is insensitive to load factor.

References

H1 Options Appraisal of NO_x Abatement Measures for Aberthaw Power Station (ENV/505/2012)

Appendix A. Air Quality Impact Assessment

Aberthaw Low NOx Boilers: Air Impact Assessment

Reference Number: ENV/587/2015
Date: June 2015
Issue: 1
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Aberthaw Low NOx Boilers: Air Impact Assessment

Prepared for:

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Contract No. :	

Prepared by: Paul Sutton	

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Summary

Proposed low NO_X boiler modifications at Aberthaw Power Station will reduce its NO_X emissions and their resulting ground level impacts. This report assesses these reduced impacts against the relevant standards for the protection of human health and designated nature conservation sites.

For the purposes of assessing the reduction in impacts, three emissions scenarios were modelled. The impacts will depend on both the emission concentration and the load factor and a wide range of combinations are possible depending on the timing of the modification and future load factors. Therefore, the scenarios were chosen to represent the possible **range** of impacts over the next few years against a pre-modification baseline scenario. The scenarios modelled were:

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Table of contents

1 Introduction

Proposed low NO_X boiler modifications at Aberthaw Power Station will reduce its NO_X emissions and their resulting ground level impacts. This report assesses these reduced impacts against the relevant standards for the protection of human health and designated nature conservation sites.

2 Air quality and deposition standards

2.1 Human health

The Air Quality Standards (Wales) Regulations 2010 (SI 2010/1433) implement the European Union's most recent Ambient Air Quality Directive (2008/50/EC). This directive includes limit values for SO_2, NO_2, CO, PM_{10} and $PM_{2.5}$. The onus is on central government to ensure that the limit values are met.

The Air Quality Strategy for England, Scotland, Wales and Northern Ireland (Defra et al., 2007) establishes the policy for ambient air quality for the UK and sets out the National Air Quality Objectives (NAQOs). Those included in the Local Air Quality Management (LAQM) regime for the protection of human health are prescribed in the Air Quality (Wales) Regulations 2000 (SI 2000/1940) and the Air Quality (Amendment) (Wales) Regulations 2002 (SI 2002/3182). Unlike the EU limit values, which are mandatory, there is no legal obligation to meet NAQOs, although local authorities must work towards their attainment within their jurisdictions. The Environment Agency has responsibility for regulating emissions from large point sources such as power stations.

Table 1 shows the current EU limit values and NAQOs for the protection of human health relevant to the emissions from Aberthaw Power Station that were not screened out as "insignificant" by the H1 assessment for the existing Environmental Permit (Hunter, 2006). This H1 screening assessment (assuming LCPD emission limits) will be conservative relative to results with the proposed low NO_X boiler modifications and the new emission limits under the Industrial Emissions Directive (IED, 2010/75/EU), as emissions will be reduced relative to the H1 assessment, whereas the volume flux and stack gas temperature will remain essentially unchanged (temperature unchanged and volume flux within about 10% of value assumed in Hunter, 2006).

Table 1: EU limit values and national air quality objectives for the protection of human health

Substance	Objective		Date to be achieved by and maintained thereafter
	Concentration	Measured as	
Sulphur dioxide (SO_2)	266µg/m^3 (100ppb) not to be exceeded more than 35 times a year (99.9th percentile)	15 minute mean	31st December 2005[a]
	350µg/m^3 (132ppb) not to be exceeded more than 24 times a year (99.73rd percentile)	1 hour mean	31st December 2004[a]
			1st January 2005[b]
	125µg/m^3 (47ppb) not to be exceeded more than 3 times a year (99.18th percentile)	24 hour mean	31st December 2004[a]
			1st January 2005[b]
Nitrogen dioxide (NO_2)	200µg/m^3 (105ppb) not to be exceeded more than 18 times a year (99.8th percentile)	1 hour mean	31st December 2005[a]
			1st January 2010[b]
	40µg/m^3 (21ppb)	Annual mean	31st December 2005[a]
			1st January 2010[b]

[a]NAQO
[b]EU limit value

2.2 Vegetation and ecosystems

With respect to air quality impacts, Table 2 shows the EU critical levels and NAQOs for the protection of vegetation and ecosystems relevant to the emissions from Aberthaw Power Station. The regulatory agencies have agreed with the nature conservation agencies that these objectives should be applied at all nature conservation sites regardless of their location (Environment Agency, 2011a), although the EU Ambient Air Quality Directive and UK Air Quality Strategy indicate that they should not apply when in proximity to major, potentially polluting activities.

Table 2: EU critical levels and national air quality objectives for the protection of vegetation and ecosystems

Substance	Objective		Date to be achieved by and maintained thereafter
	Concentration	Measured as	
Sulphur dioxide (SO_2)	20µg/m^3 (8ppb)	Annual mean & winter mean (1st October to 31st March)	31st December 2000[a]
			19th July 2001[b]
Nitrogen oxides (NO_x, as NO_2)	30µg/m^3 (16ppb)	Annual mean	31st December 2000[a]
			19th July 2001[b]

[a]NAQO
[b]EU critical level

In addition, WHO and UNECE have published the critical levels for the protection of vegetation and ecosystems set out in Table 3. According to the Environment Agency guidance for H1 environmental risk assessments (Environment Agency, 2011a), these are to be applied at all nature conservation sites. There are further, more stringent, critical levels for the protection of lichen, but these are not relevant to the current assessment, as there are no lichen features present at the nature conservation sites local to Aberthaw Power Station.

Table 3: Additional critical levels for ammonia and NO_X

Substance	Objective	
	Concentration	Measured as
Nitrogen oxides (NO_x, as NO_2)	75µg/m^3	Daily mean[a]
Ammonia (NH_3)	3µg/m^3	Annual mean[b]
	270µg/m^3	Daily mean[a]

[a] WHO
[b] UNECE

According to the most recent Environment Agency guidance (Environment Agency, 2011a), air quality and deposition impacts should be assessed at the following nature conservation sites local to a coal-fired power station:

- Natura 2000 sites and Sites of Special Scientific Interest (SSSIs) within 15 km (distance criterion for SSSIs subject to discussion with the permitting officer).
- National Nature Reserves (NNRs), Local Nature Reserves (LNRs), Local Wildlife Sites (LWSs) and ancient woodland within 2km.

Acid and nutrient nitrogen deposition impacts at Natura 2000 sites (European sites protected by the Habitats Directive, 92/43/EEC) and SSSIs (protected by the Countryside and Rights of Way Act 2000) are assessed against minimum site-relevant critical loads (SRCLs) obtained from the UK Air Pollution Information System (APIS, http://www.apis.ac.uk/). For other types of site, no site-relevant critical loads are available, so critical loads are obtained from the APIS database on the basis of site location and dominant habitat type.

In the assessment of impacts on nature conservation sites for the existing Environmental Permit (JEP, 2006), air quality and deposition impacts were assessed for all Natura 2000 sites and SSSIs within 15 km of Aberthaw Power Station, with a further national-scale assessment of deposition impacts at all Natural 2000 sites in the UK. The current assessment considers air quality and deposition impacts at all Natura 2000 sites and SSSIs within 15km, plus all NNRs, LNRs, LWSs and ancient woodland sites within 2 km.

As deposition impacts are expected to reduce when low NO_X boilers are installed, the national assessment of deposition impacts has not been repeated. Instead, this assessment focuses on updating the previous assessment of local impacts, taking account of the additional sites within 2 km, and any revisions to SRCLs for Natura 2000 sites and SSSIs within 15 km. As the NH_3 emissions from Aberthaw Power Station are very small compared to NO_2 and NO emissions, they have not been included in the modelling for this assessment. The station contribution to nutrient nitrogen deposition impacts is estimated from the sum of NO_2 and NO deposition, and the contribution to acidification impacts is estimated from the sum of SO_2, SO_3, HCl, NO_2 and NO deposition.

3 The receiving environment

3.1 Identification of important local receptors

3.1.1 Local population

Aberthaw Power Station is located off the B4265 between Cardiff International Airport (formerly known as Rhoose Airport) and Llantwit Major, as shown in Figure 1. The station is on the South Wales Coast some 9 km to the west of Barry, with the villages of East Aberthaw and West Aberthaw about 1.5 km and 0.5 km to the east and northwest of the power station respectively. Directly north of the power station site, at a distance of about 1.5 km, is the Barry to Bridgend railway line and a cement works. Cardiff Airport is 4 km to the east and the M4 motorway is 15 km to the north. The power station site and surrounding land area (out to a distance of about 13 km) lie within the area of jurisdiction of the Vale of Glamorgan Council.

According to the Air Quality Standards (Wales) Regulations 2010, EU limit values for the protection of human health apply at all locations except the workplace, but only need to be assessed at locations where members of the public have regular access. The technical guidance on local air quality management (LAQM.TG(09); Defra, 2009) provides advice on where the NAQOs should be applied. Annual mean objectives apply at all outdoor locations where members of the public might be regularly exposed, for example, façades of residential properties, schools, hospitals and care homes. Daily mean objectives (as for SO_2) also apply at hotels and gardens of residential properties (typically this excludes front gardens).

In addition to the locations where the annual and daily objectives apply, the hourly mean NAQOs (SO_2 and NO_2) apply at kerbside sites (e.g. the pavements of busy shopping centres), those parts of car parks and bus and railway stations which are not fully enclosed, and any other outdoor locations where the public might reasonably be expected to spend one hour or longer. The NAQO for 15 minute SO_2 concentrations applies at all outdoor locations where members of the public might reasonably be exposed for a period of 15 minutes or longer.

For areas where an NAQO is unlikely to be met, the local authority must designate an Air Quality Management Area (AQMA) and draw up an Air Quality Action Plan (AQAP) setting out the measures it intends to introduce to meet the objectives within the AQMA. However, there are no AQMAs to be taken into account when assessing the impacts of Aberthaw Power Station, as there are no AQMAs within 15 km of the power station.

Rather than modelling impacts at individual sensitive local receptors, the current assessment compares EU limit values and NAQOs for the protection of human health with modelled concentrations at the point of predicted maximum impact across the whole of the output grid for five years of meteorological data. This is a conservative approach and takes account of any spatial uncertainties in the modelling results.

3.1.2 Nature conservation sites

With regard to the protection of vegetation and ecosystems at designated nature conservation sites, Dunraven Bay SAC (a limestone headland, not sensitive to acid deposition) and the Sully Island component of the Severn Estuary SPA are the only Natura 2000 sites within 15 km of the power station (Figure 2). However impacts at Kenfig/Cynffig SAC, about 18 km northwest of the power station, are also considered in this assessment as, historically, this has been a site of particular concern with respect to atmospheric nitrogen deposition from power station emissions (CCW, 2008).

For modelling purposes (see details in Appendix A), these Natura 2000 sites are assumed to be located at OS grid references (288600,172700), (3167000,167000) and

(287500,176500) respectively. The location assumed for Dunraven Bay is the approximate central point of the SAC according to the JNCC website (http://jncc.defra.gov.uk/) and, as the site covers only 6.47 ha, impacts at this point should be representative of the whole site. For the Severn Estuary, the modelled receptor point is the grid reference provided in the site citation for the Sully Island SSSI (http://www.ccw.goc.uk), and for Kenfig, the grid reference is the site location closest to Aberthaw Power Station, where station impacts are likely to be greatest.

There are 23 SSSIs within 15 km of Aberthaw Power Station (Figure 2), of which three (Barry Island, Cnap Twt, and Hayes Point to Bendrick Rock) are of geological interest only and not sensitive to atmospheric impacts. The 20 SSSIs within 15 km which are potentially susceptible to atmospheric impacts are listed in Table 4. Unless noted, the National Grid references (NGRs) for the SSSIs are those provided in the site citations (http://www.ccw.gov.uk/). The locations given in Table 4 are the receptor points used in the modelling described later (Appendix A).

Table 4: Relevant SSSIs within 15km of Aberthaw Power Station

Site	Designation	NGR
Breigam Moor	SSSI	298600,179400
Clemenstone Meadows, Wick	SSSI	292000,173900
Cliff Wood – Golden Stairs	SSSI	309100,167000
Coed y Bwl	SSSI	290900,175200
Coedydd y Barri/Barry Woodlands	SSSI	308700,169000[a]
Cog Moors	SSSI	315800,169400
Cors Aberthin	SSSI	300300,175500
Cosmeston Park	SSSI	317300,169300
East Aberthaw Coast	SSSI	304200,165800
Ely Valley	SSSI	307500,176000[b]
Larks Meadows	SSSI	293100,170200
Llynnoedd Cosmeston/Cosmeston Lakes	SSSI	317400,169100
Monknash Coast	SSSI	293400,167600[b]
Nant Whitton Woodlands	SSSI	306200,171500
Nash Lighthouse Meadow	SSSI	292000,168000
Old Castle Down	SSSI	290500,175800[c]
Pysgodlyn Mawr	SSSI	304100,176100[d]
Southerndown Coast	SSSI	289700,171700[b]
Sully Island	SSSI	316700,167000
The Parish Field, Cae'r Rhedyn	SSSI	297900,177600

[a]NGR for group of woodlands closest to Aberthaw Power Station.
[b]NGR for point closest to Aberthaw Power Station.
[c]NGR on site citation incorrectly given as 280500,175800.
[d]NGR on site citation incorrectly given as 316800,166900.

Information provided by the Vale of Glamorgan Council (Rowe, 2013) indicates that there are no NNRs or LNRs within 2 km of Aberthaw Power Station. However, there are 14 LWSs and three ancient woodland sites which are wholly or partially within 2 km of the station; all three ancient woodland sites are also LWSs. Details of the LWSs and ancient woodland are shown in Table 5 and Figure 2, where Site of Importance for Nature

Conservation (SINC) is the local terminology for LWS (LWS is a generic term). The NGRs are the points on the 15 km x 15 km air quality modelling receptor grid (Appendix A) closest to the relevant SINC; where more than one grid point would be appropriate for the site, the point where the modelled station impact is greatest was chosen.

Table 5: LWSs (known locally as SINCs) and ancient woodland within 2 km of Aberthaw Power Station

Site	Designation	NGR	Habitat type
Castle Wood	SINC & ancient woodland	305000,167500	Broadleaved woodland
Coast at Aberthaw Power Station	SINC	301500,166500	Coastal vegetated shingle
Coed Llancadle	SINC & ancient woodland	303000,168000	Broadleaved woodland
East Aberthaw Former Quarry	SINC	303500,167000	Lowland calcareous grassland
East Orchard Wood	SINC & ancient woodland	302000,168000	Broadleaved woodland
Land adjacent to Burton Plantation	SINC	303500,168000	Lowland calcareous grassland
Land at East Aberthaw	SINC	304000,166000	Lowland meadows & lowland calcareous grassland
Land South of Llancadle	SINC	303500,168000	Coastal grazing marsh
Lower Thaw Valley	SINC	303000,167000	Coastal grazing marsh
North of Aberthaw Cement Works	SINC	303000,167500	Lowland meadows
Ox Moor	SINC	303000,168500	Coastal grazing marsh
Oxmoor Wood	SINC & ancient woodland	302500,168500	Broadleaved woodland
The Walls at Aberthaw	SINC	301000,166500	Lowland calcareous grassland
Walls Pool at Aberthaw	SINC	301000,166500	Coastal saltmarsh

3.2 Background air concentrations and deposition rates

Table 6 summarises recent measured annual mean NO_2 concentrations from the three air quality monitoring stations in the vicinity of Aberthaw Power Station (Figure 1). The monitoring sites at Font-y-Gary (Aberthaw East, NGR 305300,166100) and Seaview Farm (Aberthaw West, NGR 300200,167300) were operated by RWE Generation UK plc as part of Aberthaw Power Station's Air Quality Strategy (AQS) Management Plan (the Seaview Farm monitoring station closed on 15 September 2011 and Font-y-Gary in June 2015). The site at the Highwayman Inn, Fonmon (NGR 305800,167300) is a supplementary site operated by the Vale of Glamorgan Council, which closed on 27 May 2014. The results in Table 6 are taken from the RWE npower Annual Reviews of the AQS Management Plan (Whitwell, Salway and Wright, 2011, Whitwell and Salway, 2012, and Whitwell, Salway and Osborne, 2013).

Table 6: Measured NO_2 concentrations close to Aberthaw Power Station (µg/m^3)

Statistic	Monitoring station	Year			
		2010	2011	2012	2013
Annual mean NO_2 concentration	Font-y-Gary	15	12.4	12.9	12.1
	Seaview Farm	14	10.7*	N/A	N/A
	Highwayman Inn	12	12.5	11.5	10.7

* Seaview Farm monitoring station closed on 15 September 2011, so results are not representative of whole year.

N/A Not available.

Although the statistics shown in Table 6 include contributions from local sources (the power station and cement works in particular), these measurements are the most representative available continuously monitored data on background concentrations in the immediate vicinity of the power station and, therefore, the most suitable for use in assessing air quality impacts on human health (Section 5.1).

The annual mean NO_2 concentrations in Table 6 are close to the Defra prediction of 11.4 µg/m^3 (http://laqm.defra.gov.uk/, 2010 base year map) for 2010 annual mean background NO_2 concentrations close to the location of maximum plume impact from Aberthaw Power Station (1km^2 grid square centred at NGR coordinates 305500,166500).

The values for background NO_X concentrations and rates of acid and nutrient nitrogen deposition used in the assessment of impacts at local Natura 2000 sites, SSSIs and SINCs (Section 5.2) have been obtained from the APIS database. All background values from APIS are 3-year averages for 2009-11 at the locations specified in Section 3.1.2, and include a contribution from Aberthaw Power Station without the low NO_X boiler modifications.

3.3 Air quality impacts due to power station operations without the low NO_X boiler modifications

Air quality modelling (Hunter, 2006) for the current Aberthaw Power Station Environmental Permit gave the results shown in Table 7 for NO_2 concentrations at the point of maximum plume impact. These are the maximum likely station impacts for operations with FGD, but without the low NO_X boiler modifications, and take no account of background concentrations. Station impacts on ground level concentrations of NO_2 are expected to reduce after the low NO_X boiler modifications.

Table 7: NO_2 modelling results at the locations of greatest impact from Aberthaw Power Station with FGD only (µg/m^3) – no background included

Statistic	Meteorological data year				
	1993	1994	1995	1996	1997
99.8th percentile of NO_2 hourly mean concentrations (100% load factor)	93	99	145	104	96
Number of exceedences of 200 µg/m^3 NO_2 as hourly mean (100% load factor)	0	0	1	0	0
Annual mean NO_2 concentration (80% load factor)	2.9	4.3	3.3	3.0	3.0

Note Results for NO_2 obtained using ADMS NO_X chemistry module with background ozone concentrations from Yarner Wood (Hunter, 2006).

4 Operational scenarios and emissions

For the purposes of assessing the reduction in the impacts of the power station resulting from the proposed low NO_X boiler modifications, three emissions scenarios were modelled. The impacts will depend on both the emission concentration and the load factor and a wide range of combinations are possible depending on the timing of the modification and future load factors. Therefore, the scenarios were chosen to represent the possible **range** of impacts over the next few years against a pre-modification baseline scenario. The scenarios modelled were:

Scenario 0: This scenario is representative of the high end of recent generation by Aberthaw Power Station, before the proposed low NO_X boiler modifications. In this scenario, all units are modelled as operating at 75% load factor and as having an NO_X emission concentration of 1050 mg/Nm^3 (dry, 6% O2).

Scenario 1: This scenario corresponds to the expected operation of Aberthaw immediately after the low NO_X boiler modification on one of the three Aberthaw generating units. In this scenario, all units are modelled as operating at 75% load factor. The two unmodified units are modelled as having a NO_X emission concentration of 1050 mg/Nm^3 (dry, 6% O_2). The modified unit is modelled as having a NO_X emission concentration of 600 mg/Nm^3 (dry, 6% O_2); this is a pessimistic assumption corresponding to the high end of the NO_X emission concentration range post-modification.

Scenario 2: This scenario corresponds to the possible future operation of Aberthaw after the low NO_X boiler modification on all three Aberthaw generating units. To quantify the lower end of the range of future possible future impacts, Aberthaw was assumed to operate at full load for 1500 hours with an emission concentration of 450 mg/Nm^3 (dry, 6% O^2), to represent a scenario consistent with operation within the IED 1500 hour derogation. 1500 hours corresponds to a 17.1% (=100%x1500/8760) load factor.

The emission concentration assumed for modelling of SO_2 in order to assess combined acid S and N deposition impacts was 350 mg/Nm^3 (dry, 6% O_2), i.e. the limit agreed as BAT for the period 2016 until BREF conclusions are implemented.

Primary NO_2 emissions are assumed to be 1.6% (by volume) of the total NO_x emissions. This is based on a pessimistic assumption of 5% NO_2 in the boiler, with 70% of the NO_2 removed in the FGD.

The assumed flue gas concentrations for SO_3 and HCl were based on the values used in the "Aberthaw SCR Application: Air Impact Assessment" report (Brooke, 2012). The flue gas concentration of SO_3 (likely to be present as aerosol droplets) is assumed to be 20.6 mg/Nm^3 (dry, 6% O_2) and the flue gas HCl concentration is assumed to be 2.7 mg/Nm3 (dry, 6% O2).

As the NH_3 emissions from Aberthaw Power Station are very small compared to NO_2 and NO emissions, they have not been included in the modelling for this assessment.

Long-term and short-term impacts have been assessed corresponding to the assumed load factor for each scenario.

Full details of the emission rates and other input parameters for air quality modelling are given in Appendix A.

5 Results and discussion

The proposed low NO_X boiler modifications will not result in a change in the SO_2 emission rate from Aberthaw Power Station and, therefore, would not be expected to result in a change in SO_2 air concentration impacts (for a given power station load factor). As this report is assessing the reduction in the impacts of the power station resulting from the proposed low NO_X boiler modifications, air quality standards for SO_2 air concentrations are not considered in this report.

5.1 Impacts on human health

Table 8 details the modelled NO_2 concentrations from the station for the three scenarios at the locations of maximum impact for five years of meteorological data. The mean for the five meteorological years is also shown.

Table 8: Modelled station NO_2 concentrations at the locations of maximum impact (µg/m3) (excluding background contributions)

	Statistic	Meteorological data year					
		2006	2007	2008	2009	2010	Mean
Scenario 0	99.73rd percentile of NO_2 hourly mean concentrations (75% load factor)	94	88	94	89	82	89
	Number of exceedences of 200 µg/m^3 NO_2 as hourly mean (100% load factor)	0	0	0	0	0	0
	Annual mean NO_2 concentration (75% load factor)	4.6	4.3	5.1	4.0	2.9	4.2
Scenario 1	99.73rd percentile of NO_2 hourly mean concentrations (75% load factor)	90	84	90	85	80	86
	Number of exceedences of 200 µg/m^3 NO_2 as hourly mean (100% load factor)	0	0	0	0	0	0
	Annual mean NO_2 concentration (75% load factor)	4.3	4.0	4.7	3.8	2.7	3.9
Scenario 2	98.80th percentile of NO_2 hourly mean concentrations (17% load factor)	54	50	52	50	46	50
	Number of exceedences of 200 µg/m^3 NO_2 as hourly mean (100% load factor)	0	0	0	0	0	0
	Annual mean NO_2 concentration (17% load factor)	0.6	0.6	0.7	0.6	0.4	0.6

Short-term impacts

The short-term NAQO is on the 99.80th percentile of NO_2 hourly mean concentrations for all hours in a year. As the station is modelled as operating at 75% load factor in Scenarios 0 and 1, the statistic for concentrations from the station (excluding background) has been adjusted to be the 99.73rd percentile of NO_2 hourly mean concentrations. As the station is modelled as operating at 17% load factor in Scenario 2, the statistic for concentrations from the station has been adjusted to be the 98.80th percentile of NO_2 hourly mean concentrations. The results in Table 8 show that for Scenario 0, the modelled 99.73rd percentile of NO_2 hourly mean concentrations from the station at the locations of maximum impact are less than 50% of the short-term NAQO (200 µg/m^3). Following H1 guidance, the total NO_2 impacts can be estimated by adding a background contribution given by twice the annual mean background concentration. A pessimistic estimate of the annual mean background concentration can be obtained from the measured annual mean NO_2 concentration close to Aberthaw power station given in Table 6 (which include a contribution from Aberthaw power station). The largest measured annual mean NO_2 concentration in the table is 15µg/m^3 at Font-y-Gary, which gives a background contribution to the total NO_2 concentration of 30µg/m^3. The resulting total NO_2 concentration estimate for scenario 0 is less than 75% of the NAQO. It can be seen in Table 8 that scenario 1 results in the predicted station contribution to the 99.73rd percentile of NO_2 hourly mean concentration at the location of maximum impact reducing by 3% and that scenario 2 results in the predicted station contribution to the 99.73rd percentile of NO_2 hourly mean concentration at the location of maximum impact reducing by 14%.

Long-term impacts

The results in Table 8 show that for scenario 0, the modelled annual mean NO_2 concentration from the station at the locations of maximum impact are less than 11% of the long-term NAQO (40 µg/m^3) (using the mean value from all meteorological years). Using the largest measured annual mean NO_2 concentration in the table 6 of 15µg/m^3 for the background contribution to the total NO_2 concentration gives a total NO_2 concentration estimate for scenario 0 of 19.2 µg/m^3 (using the mean value from all meteorological years); this is less than 50% of the NAQO. It can be seen in Table 8 that scenario 1 results in the modelled station contribution to the annual mean NO_2 concentration reducing by 7% and that scenario 2 results in the modelled station contribution to the annual mean NO_2 concentration reducing by 85%.

5.2 Impacts on nature conservation sites

5.2.1 Methodology

Following the methodology described in the Environment Agency's H1 environmental risk assessment framework for air emissions (Environment Agency, 2011a) and the Environment Agency guidance for assessments of impacts on Natura 2000 sites (Environment Agency, 2007), the following thresholds were used to determine when power station contributions were not "likely to have a significant effect" on designated conservation sites:

- Station contribution <10% of short-term critical level
- Station contribution <1% of long-term critical level or critical load

For sites other than Natura 2000 sites, these screening criteria may be over-precautionary, as other types of site have a lower degree of statutory protection. Under the Habitats Directive, there is a requirement to demonstrate that a plan or project will "not adversely affect" the integrity of a Natura 2000 site before permission can be granted. In contrast, SSSIs are protected by the Countryside and Rights of Way (CROW) Act 2000, where the requirement is to notify the relevant nature conservation agency only if permitted operations are "likely to damage" any of the relevant features of the SSSI. Local Wildlife Sites (which include SINCs) have non-statutory protection.

Significance screening relative to the critical load for acid deposition is not straightforward, as the critical load function (shown in Figure 3) is defined in terms of the following three parameters:

$CL_{max}S$ = maximum critical load for sulphur deposition
$CL_{max}N$ = maximum critical load for nitrogen deposition
$CL_{min}N$ = minimum critical load for nitrogen deposition (below which nitrogen has no effect on acidity)

The acidity critical load parameters for all nature conservation sites local to Aberthaw Power Station are given in Appendix B.

According to the most recent Environment Agency methodology, implemented by the APIS Critical Load Function Tool (http://www.apis.ac.uk/critical-load-function-tool), the method for calculating the station contribution (equivalent to H1 "Process Contribution", PC) is dependent on the predicted total deposition (equivalent to H1 "Predicted Environmental Concentration", PEC) as follows:

When PEC N deposition < $CL_{min}N$,
PC as % CL function = (PC S deposition/$CL_{max}S$) x 100

When PEC N deposition > $CL_{min}N$,
PC as % CL function = ((PC S+N deposition)/$CL_{max}N$) x 100

Thus only the contribution to sulphur deposition needs to be assessed if total nitrogen deposition is less than $CL_{min}N$. In all other cases (the majority), the combined inputs of sulphur and nitrogen deposition are assessed relative to $CL_{max}N$. The background rates of nitrogen and sulphur deposition used in the assessment are given in Appendix C.

5.2.2 Air quality impacts

The annual mean NO_X concentration from the station (excluding background) was modelled for each of the nature conservation sites for the three scenarios for five years of meteorological data. The mean values for the five meteorological years were calculated for each of the nature conservation sites for each of the three scenarios and are shown in Table 9 as a % of the critical level (30 µg/m^3). The table also shows the total annual mean NO_X concentration as a % of the critical level for each of the nature conservation sites for each of the three scenarios, calculated using the background annual mean NO_X concentrations for each of the nature conservation sites obtained from APIS, listed in Table C1. The results in Table 9 for scenario 0 show that the predicted station contribution to annual mean NOx for all the nature conservation sites is equal to or greater than the 1% significance screening threshold. However, it can also be seen in Table 9 that all the total annual mean NOx concentrations are less than 60% of the critical level and, so, it is very unlikely that there will be any adverse effects associated with long-term NO_X concentrations due to emissions from Aberthaw Power Station. It can be seen in Table 9 that Scenario 1 results in the modelled station contribution to the NO_X concentration reducing by 14% and for Scenario 2 by 90%, for all the nature conservation sites.

The maximum daily mean NO_X concentration from the plant alone during a calendar year was modelled for each of the nature conservation sites for the three scenarios for five years of meteorological data. The average value for the five meteorological years was calculated for each of the nature conservation sites for each of the three scenarios and is shown in Table 10 as a % of the critical level (75 µg/m^3). The maximum total daily mean NO_X concentration was calculated using the pessimistic assumption that it is equal to the maximum station daily mean NO_X concentration plus the background annual mean NO_X concentrations. Table 10 shows the maximum total daily mean NO_X concentration as a % of the critical level for each of the nature conservation sites for each of the three scenarios. The results in Table 10 for scenario 0 show that the predicted station contribution to maximum daily mean NOx for all the nature conservation sites is equal to or greater than the 10% significance screening threshold. However, it can also be seen in Table 10 that the maximum total daily mean NO_X concentration exceeds the critical level at only 1 SSSI site and 3 SINC sites. It can be seen in Table 10 that scenario 1 results in the modelled station contribution to the NO_X concentration reducing by 14% and that scenario 2 results in the modelled station contribution to the NO_X concentration reducing by 57%, for all the nature conservation sites. For scenario 2, all maximum total daily mean NO_X concentrations are less than 80% of the critical level.

Table 9: Annual mean NO_X concentration relative to the critical level at nature conservation sites

Nature conservation site	Critical level (µg/m^3)	Scenario 0		Scenario 1		Scenario 2	
		Max station contribution as % of critical level	Total concentration as % of critical level	Max station contribution as % of critical level	Total concentration as % of critical level	Max station contribution as % of critical level	Total concentration as % of critical level
Dunraven Bay SAC	30	3.1	28.1	2.7	27.7	0.3	25.3
Kenfig/Cynffig SAC	30	2.7	34.7	2.3	34.3	0.3	32.3
Severn Estuary SPA	30	11.5	53.1	9.8	51.5	1.1	42.8
Breigam Moor SSSI	30	3.0	38.7	2.6	38.2	0.3	36.0
Clemenstone Meadows, Wick SSSI	30	3.5	30.2	3.0	29.7	0.3	27.0
Cliff Wood - Golden Stairs SSSI	30	20.1	57.8	17.2	54.9	2.0	39.6
Coed y Bwl SSSI	30	3.3	47.6	2.8	47.2	0.3	44.7
Coedydd y Barri/Barry Woodlands SSSI	30	14.7	52.4	12.6	50.3	1.4	39.1
Cog Moors SSSI	30	10.9	52.6	9.4	51.0	1.1	42.7
Cors Aberthin SSSI	30	3.6	40.3	3.1	39.8	0.4	37.0
Cosmeston Park SSSI	30	10.1	51.8	8.7	50.4	1.0	42.7
East Aberthaw Coast SSSI	30	13.7	44.4	11.8	42.4	1.3	32.0
Ely Valley SSSI	30	3.3	53.3	2.8	52.8	0.3	50.3
Larks Meadows SSSI	30	4.1	30.8	3.5	30.2	0.4	27.1
Llynnoedd Cosmeston/Cosmeston Lakes SSSI	30	10.2	51.8	8.7	50.4	1.0	42.7
Monknash Coast SSSI	30	3.6	26.6	3.1	26.1	0.4	23.4
Nant Whitton Woodlands SSSI	30	4.9	41.9	4.2	41.2	0.5	37.5
Nash Lighthouse Meadow SSSI	30	3.4	26.4	2.9	25.9	0.3	23.3
Old Castle Down SSSI	30	3.2	47.6	2.8	47.1	0.3	44.7
Pysgodlyn Mawr SSSI	30	2.6	39.3	2.3	38.9	0.3	36.9
Southerndown Coast SSSI	30	3.4	28.4	2.9	27.9	0.3	25.3
Sully Island SSSI	30	11.5	53.1	9.8	51.5	1.1	42.8
The Parish Field, Cae’r Rhedyn SSSI	30	3.6	39.2	3.0	38.7	0.3	36.0
Castle Wood SINC*	30	20.1	57.8	17.2	54.9	2.0	39.6
Coast at Aberthaw Power Station SINC	30	1.4	31.7	1.2	31.5	0.1	30.5
Coed Llancadle SINC*	30	2.6	32.9	2.2	32.5	0.3	30.6
East Aberthaw Former Quarry SINC	30	7.8	38.4	6.7	37.3	0.8	31.4
East Orchard Wood SINC*	30	4.0	34.3	3.4	33.7	0.4	30.7
Land adjacent to Burton Plantation SINC	30	4.0	34.7	3.4	34.1	0.4	31.1
Land at East Aberthaw SINC	30	15.3	45.9	13.1	43.8	1.5	32.2
Land South of Llancadle SINC	30	4.0	34.7	3.4	34.1	0.4	31.1
Lower Thaw Valley SINC	30	2.4	33.1	2.1	32.7	0.2	30.9
North of Aberthaw Cement Works SINC	30	2.5	32.8	2.1	32.5	0.2	30.6
Ox Moor SINC	30	2.7	33.1	2.4	32.7	0.3	30.6
Oxmoor Wood SINC*	30	2.9	33.6	2.5	33.1	0.3	30.9
The Walls at Aberthaw SINC	30	3.1	33.8	2.7	33.3	0.3	31.0
Walls Pool at Aberthaw SINC	30	3.1	33.8	2.7	33.3	0.3	31.0

* Ancient woodland site as well as SINC.

Table 10: Daily mean NO_X concentration relative to the critical level at nature conservation sites

Nature conservation site	Critical level (µg/m³)	Scenario 0		Scenario 1		Scenario 2	
		Max station contribution as % of critical level	Total concentration as % of critical level	Max station contribution as % of critical level	Total concentration as % of critical level	Max station contribution as % of critical level	Total concentration as % of critical level
Dunraven Bay SAC	75	29.8	39.8	25.5	35.5	12.8	22.8
Kenfig/Cynffig SAC	75	28.7	41.5	24.6	37.4	12.3	25.1
Severn Estuary SPA	75	46.9	63.5	40.2	56.8	20.1	36.8
Breigam Moor SSSI	75	31.3	45.6	26.8	41.1	13.4	27.7
Clemenstone Meadows, Wick SSSI	75	39.1	49.8	33.5	44.2	16.8	27.4
Cliff Wood - Golden Stairs SSSI	75	71.9	86.9	61.6	76.7	30.8	45.9
Coed y Bwl SSSI	75	36.9	54.7	31.6	49.4	15.8	33.6
Coedydd y Barri/Barry Woodlands SSSI	75	80.5	95.6	69.0	84.1	34.5	49.6
Cog Moors SSSI	75	40.7	57.3	34.9	51.5	17.4	34.1
Cors Aberthin SSSI	75	37.8	52.5	32.4	47.1	16.2	30.9
Cosmeston Park SSSI	75	39.1	55.8	33.6	50.2	16.8	33.5
East Aberthaw Coast SSSI	75	116.2	128.4	99.6	111.8	49.8	62.1
Ely Valley SSSI	75	35.3	55.3	30.3	50.3	15.1	35.1
Larks Meadows SSSI	75	42.0	52.7	36.0	46.7	18.0	28.7
Llynnoedd Cosmeston/Cosmeston Lakes SSSI	75	39.6	56.3	34.0	50.6	17.0	33.7
Monknash Coast SSSI	75	38.6	47.8	33.1	42.3	16.6	25.8
Nant Whitton Woodlands SSSI	75	50.2	65.0	43.0	57.8	21.5	36.3
Nash Lighthouse Meadow SSSI	75	35.7	44.9	30.6	39.8	15.3	24.5
Old Castle Down SSSI	75	35.6	53.4	30.5	48.3	15.3	33.0
Pysgodlyn Mawr SSSI	75	34.3	49.0	29.4	44.1	14.7	29.4
Southerndown Coast SSSI	75	33.7	43.7	28.9	38.9	14.4	24.4
Sully Island SSSI	75	46.9	63.5	40.2	56.8	20.1	36.8
The Parish Field, Cae’r Rhedyn SSSI	75	34.4	48.7	29.5	43.8	14.8	29.0
Castle Wood SINC*	75	143.0	158.0	122.5	137.6	61.3	76.4
Coast at Aberthaw Power Station SINC	75	32.0	44.1	27.4	39.5	13.7	25.8
Coed Llancadle SINC*	75	60.1	72.3	51.5	63.7	25.8	37.9
East Aberthaw Former Quarry SINC	75	101.4	113.7	86.9	99.2	43.5	55.8
East Orchard Wood SINC*	75	67.9	80.1	58.2	70.4	29.1	41.3
Land adjacent to Burton Plantation SINC	75	63.8	76.1	54.7	66.9	27.4	39.6
Land at East Aberthaw SINC	75	112.2	124.5	96.2	108.5	48.1	60.4
Land South of Llancadle SINC	75	63.8	76.1	54.7	66.9	27.4	39.6
Lower Thaw Valley SINC	75	56.4	68.6	48.3	60.6	24.2	36.4
North of Aberthaw Cement Works SINC	75	62.7	74.9	53.8	65.9	26.9	39.0
Ox Moor SINC	75	56.2	68.3	48.1	60.3	24.1	36.2
Oxmoor Wood SINC*	75	83.8	96.1	71.8	84.1	35.9	48.2
The Walls at Aberthaw SINC	75	65.0	77.2	55.7	67.9	27.9	40.1
Walls Pool at Aberthaw SINC	75	65.0	77.2	55.7	67.9	27.9	40.1

* Ancient woodland site as well as SINC.

5.2.3 Deposition impacts

The annual nutrient nitrogen deposition from the plant alone (excluding background) was modelled for each of the nature conservation sites for the three scenarios for five years of meteorological data. The average value for the five meteorological years was calculated for each of the nature conservation sites for each of the three scenarios and is shown in Table 11 as a % of the critical load (which are also shown in Table 11). The table also shows the total annual nutrient nitrogen deposition as a % of the critical load for each of the nature conservation sites for each of the three scenarios, calculated using the background annual nutrient nitrogen deposition for each of the nature conservation sites obtained from APIS, listed in Table C1. The results in Table 11 for scenario 0 show that the predicted station contribution to annual nutrient nitrogen deposition to be greater than the 1% significance threshold at seven SSSI sites and six SINC sites. At all seven SSSI sites, the total annual nutrient nitrogen deposition is greater than the critical load. At four of the SINC sites, the total annual nutrient nitrogen deposition is greater than the critical load. It can be seen in Table 11 that scenario 1 results in the modelled station contribution to the annual nutrient nitrogen deposition reducing by 10% and that scenario 2 results in the modelled station contribution to the annual nutrient nitrogen deposition reducing by 88%. For scenario 2, the predicted station contribution to annual nutrient nitrogen deposition is greater than the 1% significance threshold at 3 SSSI sites and 1 SINC site, but is less than 3% of the critical load; the total annual nutrient nitrogen deposition is greater than the critical load at all 4 of these sites.

The annual acid deposition from the plant alone (not including background) was modelled for each of the nature conservation sites for the three scenarios for five years of meteorological data. The average value for the five meteorological years was calculated for each of the nature conservation sites for each of the three scenarios and is shown in Table 12 as a % of the critical load (see Table B1). The table also shows the total annual acid deposition as a % of the critical load for each of the nature conservation sites for each of the three scenarios, calculated using the background annual acid deposition for each of the nature conservation sites obtained from APIS, listed in Table C1. The results in Table 12 for scenario 0 show that the predicted station contribution to annual acid deposition to be greater than the 1% significance threshold at the Kenfig SAC and at 5 SSSI sites and 5 SINC sites. However, it can also be seen in Table 12 that all the total annual acid depositions for these 5 SSSI sites and 5 SINC sites is less than 80% of the critical load. It can also be seen that the total annual acid depositions for the Kenfig SAC is 101.0% of the critical load; so only just above the critical load. It can be seen in Table 12 that scenario 1 results in the modelled station contribution to the annual acid deposition reducing by 2% and that scenario 2 results in the modelled station contribution to the annual acid deposition reducing by 79%. For scenario 2, all the total annual acid depositions are below the critical load.

Table 11: Annual nutrient nitrogen deposition relative to the critical load at nature conservation sites

Nature conservation site	Critical load (kgN/ha/yr)	Scenario 0		Scenario 1		Scenario 2	
		Max station contribution as % of critical load	Total concentration as % of critical load	Max station contribution as % of critical load	Total concentration as % of critical load	Max station contribution as % of critical load	Total concentration as % of critical load
Dunraven Bay SAC	10	0.9	94.7	0.8	94.6	0.1	93.9
Kenfig/Cynffig SAC	8	1.0	158.5	0.9	158.4	0.1	157.6
Severn Estuary SPA	Not sensitive						
Breigam Moor SSSI	10	0.8	173.0	0.7	172.9	0.1	172.3
Clemenstone Meadows, Wick SSSI	10	1.0	160.6	0.9	160.5	0.1	159.7
Cliff Wood - Golden Stairs SSSI	5	21.9	478.3	19.7	476.1	2.6	459.0
Coed y Bwl SSSI	5	3.7	569.3	3.3	568.9	0.4	566.0
Coedydd y Barri/Barry Woodlands SSSI	5	15.7	472.1	14.2	470.6	1.9	458.3
Cog Moors SSSI	10	3.5	108.5	3.1	108.1	0.4	105.4
Cors Aberthin SSSI	10	0.9	160.5	0.8	160.4	0.1	159.7
Cosmeston Park SSSI	5	13.2	399.6	11.6	398.0	1.4	387.8
East Aberthaw Coast SSSI	Not sensitive						
Ely Valley SSSI	Unknown						
Larks Meadows SSSI	20	0.5	80.3	0.5	80.3	0.1	79.9
Llynnoedd Cosmeston/Cosmeston Lakes SSSI	Unknown						
Monknash Coast SSSI	10	0.9	97.5	0.8	97.4	0.1	96.7
Nant Whitton Woodlands SSSI	5	5.1	562.3	4.6	561.8	0.6	557.8
Nash Lighthouse Meadow SSSI	10	0.9	97.5	0.8	97.4	0.1	96.7
Old Castle Down SSSI	10	0.9	160.5	0.8	160.4	0.1	159.7
Pysgodlyn Mawr SSSI	Unknown						
Southerndown Coast SSSI	5	3.9	345.5	3.4	345.0	0.4	342.0
Sully Island SSSI	Not sensitive						
The Parish Field, Cae'r Rhedyn SSSI	20	0.5	86.6	0.4	86.5	0.1	86.2
Castle Wood SINC*	10	8.5	236.7	7.8	236.0	1.1	229.3
Coast at Aberthaw Power Station SINC	10	0.4	136.2	0.3	136.1	0.0	135.8
Coed Llancadle SINC*	10	1.1	250.3	1.0	250.2	0.1	249.3
East Aberthaw Former Quarry SINC	15	1.1	91.6	1.0	91.5	0.1	90.7
East Orchard Wood SINC*	10	1.6	250.8	1.5	250.7	0.2	249.4
Land adjacent to Burton Plantation SINC	15	0.6	91.1	0.5	91.1	0.1	90.6
Land at East Aberthaw SINC	15	2.1	92.6	1.9	92.4	0.3	90.8
Land South of Llancadle SINC	20	0.4	68.3	0.4	68.3	0.1	68.0
Lower Thaw Valley SINC	20	0.3	68.2	0.2	68.1	0.0	67.9
North of Aberthaw Cement Works SINC	20	0.3	68.2	0.2	68.1	0.0	67.9
Ox Moor SINC	20	0.3	68.2	0.3	68.2	0.0	67.9
Oxmoor Wood SINC*	10	1.2	250.4	1.0	250.2	0.1	249.3
The Walls at Aberthaw SINC	15	0.5	91.0	0.4	91.0	0.1	90.6
Walls Pool at Aberthaw SINC	20	0.4	68.3	0.3	68.2	0.0	67.9

* Ancient woodland site as well as SINC.

Table 12: Annual acid deposition relative to the critical load at nature conservation sites

Nature conservation site	Scenario 0		Scenario 1		Scenario 2	
	Max station contribution as % of critical load	Total concentration as % of critical load	Max station contribution as % of critical load	Total concentration as % of critical load	Max station contribution as % of critical load	Total concentration as % of critical load
Dunraven Bay SAC	Not sensitive					
Kenfig/Cynffig SAC	2.2	101.0	2.1	100.9	0.4	99.2
Severn Estuary SPA	Not sensitive					
Breigam Moor SSSI	Not sensitive					
Clemenstone Meadows, Wick SSSI	0.6	27.2	0.6	27.2	0.1	26.7
Cliff Wood - Golden Stairs SSSI	4.0	25.1	3.9	25.0	0.8	21.9
Coed y Bwl SSSI	0.7	26.6	0.6	26.6	0.1	26.1
Coedydd y Barri/Barry Woodlands SSSI	8.5	70.6	8.3	70.4	1.7	63.8
Cog Moors SSSI	1.8	5.0	1.8	5.0	0.4	3.7
Cors Aberthin SSSI	0.7	28.4	0.6	28.4	0.1	27.9
Cosmeston Park SSSI	6.1	59.2	5.9	59.0	1.2	54.3
East Aberthaw Coast SSSI	Not sensitive					
Ely Valley SSSI	Unknown					
Larks Meadows SSSI	0.7	28.2	0.7	28.2	0.2	27.6
Llynnoedd Cosmeston/Cosmeston Lakes SSSI	Unknown					
Monknash Coast SSSI	0.6	3.8	0.6	3.8	0.1	3.4
Nant Whitton Woodlands SSSI	2.8	76.3	2.7	76.2	0.6	74.1
Nash Lighthouse Meadow SSSI	0.6	3.8	0.6	3.8	0.1	3.4
Old Castle Down SSSI	0.6	26.8	0.5	26.7	0.1	26.3
Pysgodlyn Mawr SSSI	Unknown					
Southerndown Coast SSSI	0.7	17.1	0.7	17.1	0.1	16.5
Sully Island SSSI	Not sensitive					
The Parish Field, Cae'r Rhedyn SSSI	0.6	30.4	0.6	30.3	0.1	29.9
Castle Wood SINC*	3.8	24.9	3.8	24.8	0.8	21.9
Coast at Aberthaw Power Station SINC	0.6	3.8	0.6	3.8	0.1	3.3
Coed Llancadle SINC*	0.6	23.4	0.6	23.4	0.1	23.0
East Aberthaw Former Quarry SINC	1.8	25.2	1.8	25.2	0.4	23.8
East Orchard Wood SINC*	0.9	23.7	0.9	23.7	0.2	23.0
Land adjacent to Burton Plantation SINC	0.9	24.3	0.9	24.3	0.2	23.6
Land at East Aberthaw SINC	2.9	26.3	2.9	26.3	0.6	24.0
Land South of Llancadle SINC	1.0	28.5	1.0	28.5	0.2	27.7
Lower Thaw Valley SINC	1.0	28.5	1.0	28.5	0.2	27.7
North of Aberthaw Cement Works SINC	0.7	24.1	0.7	24.1	0.2	23.6
Ox Moor SINC	0.7	28.2	0.7	28.2	0.2	27.7
Oxmoor Wood SINC*	0.6	23.5	0.6	23.5	0.1	23.0
The Walls at Aberthaw SINC	0.7	24.2	0.7	24.1	0.2	23.6
Walls Pool at Aberthaw SINC	0.9	28.4	0.9	28.4	0.2	27.7

* Ancient woodland site as well as SINC.

6 Conclusions

The future impacts of Aberthaw Power Station will depend on both the emission concentration and the load factor and a wide range of combinations are possible depending on the timing of the modification and future load factors. Therefore, modelling was carried out to quantify the possible **range** of impacts over the next few years against a pre-modification baseline scenario.

The modelling results demonstrate that the proposed low NO_X boiler modifications will result in reductions in the impact of the power station on local air quality and deposition.

For the assessment of impacts on human health, it was found that modelled NO_2 concentrations are compliant with both short-term and long-term NAQOs for all three scenarios. The proposed low NO_X boiler modifications will result in reductions in the station's contribution to the short-term impact by between 3% and 14% and long-term impacts by between 7% and 85%.

For the assessment of impacts on nature conservation sites, it was found that the modelled annual mean NO_X concentrations are below the critical level for all sites for all three scenarios. The proposed low NO_X boiler modifications will result in reductions in the station's contribution to the impact by between 14% and 90%.

Considering the reduction in the number of sites selected by significance screening for the maximum daily mean NO_X concentrations (i.e. selecting sites for which the modelled concentration is above the critical level and the station's contribution is above the 10% screening threshold), the proposed low NO_X boiler modifications will result in between one less SINC site being selected to no sites being selected. The station's contribution to the concentration will reduce by between 14% and 57%.

Considering the reduction in the number of sites selected by significance screening for the annual nutrient nitrogen deposition (i.e. selecting sites for which the modelled deposition is above the critical load and the station's contribution is above the 1% screening threshold), the proposed low NO_X boiler modifications will result in between one less site (1 SINC site) and seven less sites (4 SSSI sites and 3 SINC sites) being selected. The station's contribution to the deposition will reduce by between 10% and 88%.

For annual acid deposition, it was found that the modelled deposition is above the critical load and the station's contribution is above the 1% screening threshold at only one site. The modelled total deposition for this site is only just above the critical load (=101.0% of the critical load). The modelling results found that the proposed low NO_X boiler modifications may result in the total deposition for this site moving below the critical load, depending on the reduction in NO_X emissions achieved and future load factors. The station's contribution to the deposition will reduce by between 2% and 79%.

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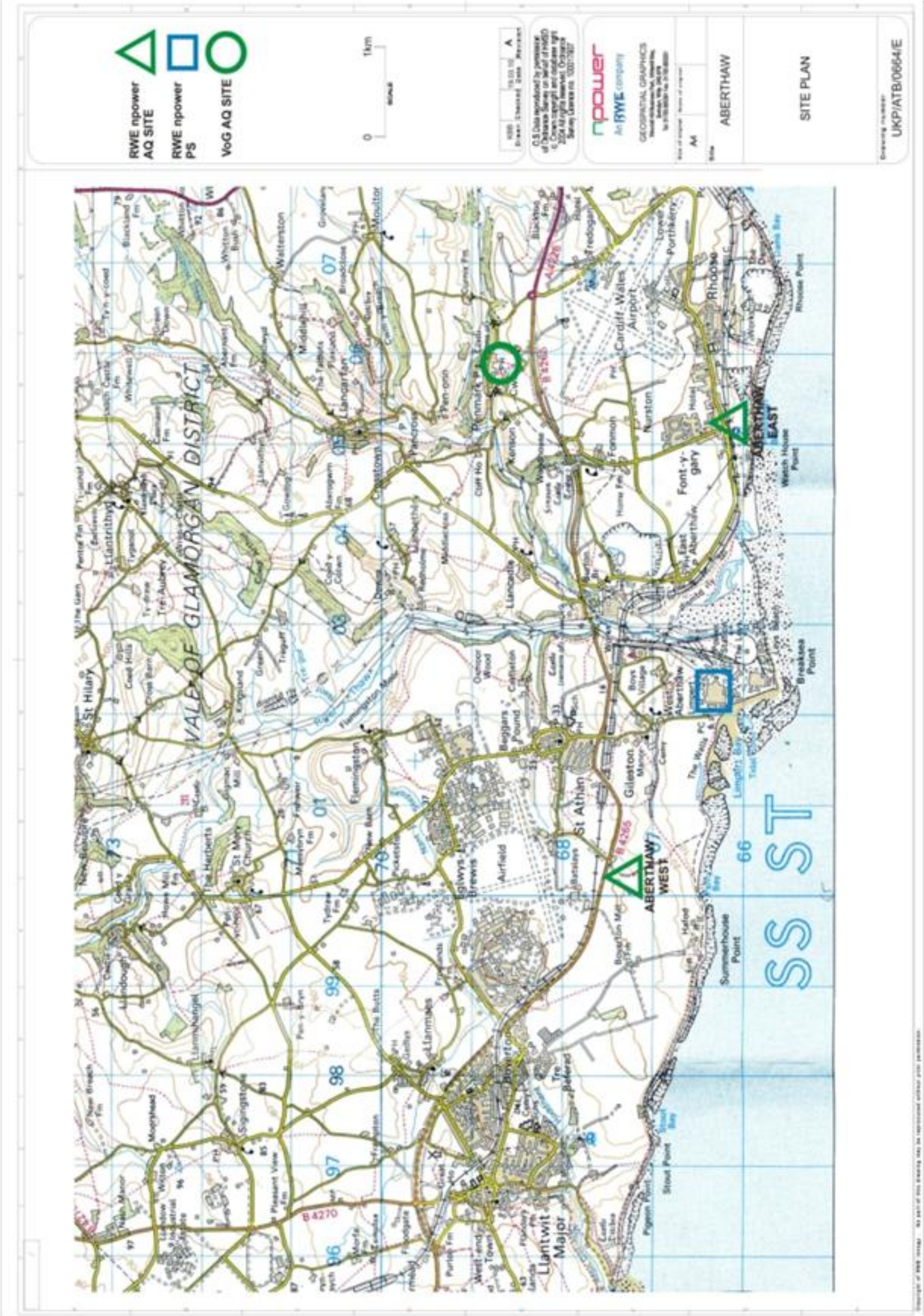

Figure 1: Map showing locations of Aberthaw Power Station and AQS Monitoring Plan air quality monitoring sites (the Aberthaw West monitoring site, also known as Seaview Farm, close on 15 September 2011 and the Aberthaw East site at Font-y-Gary in June 2015)

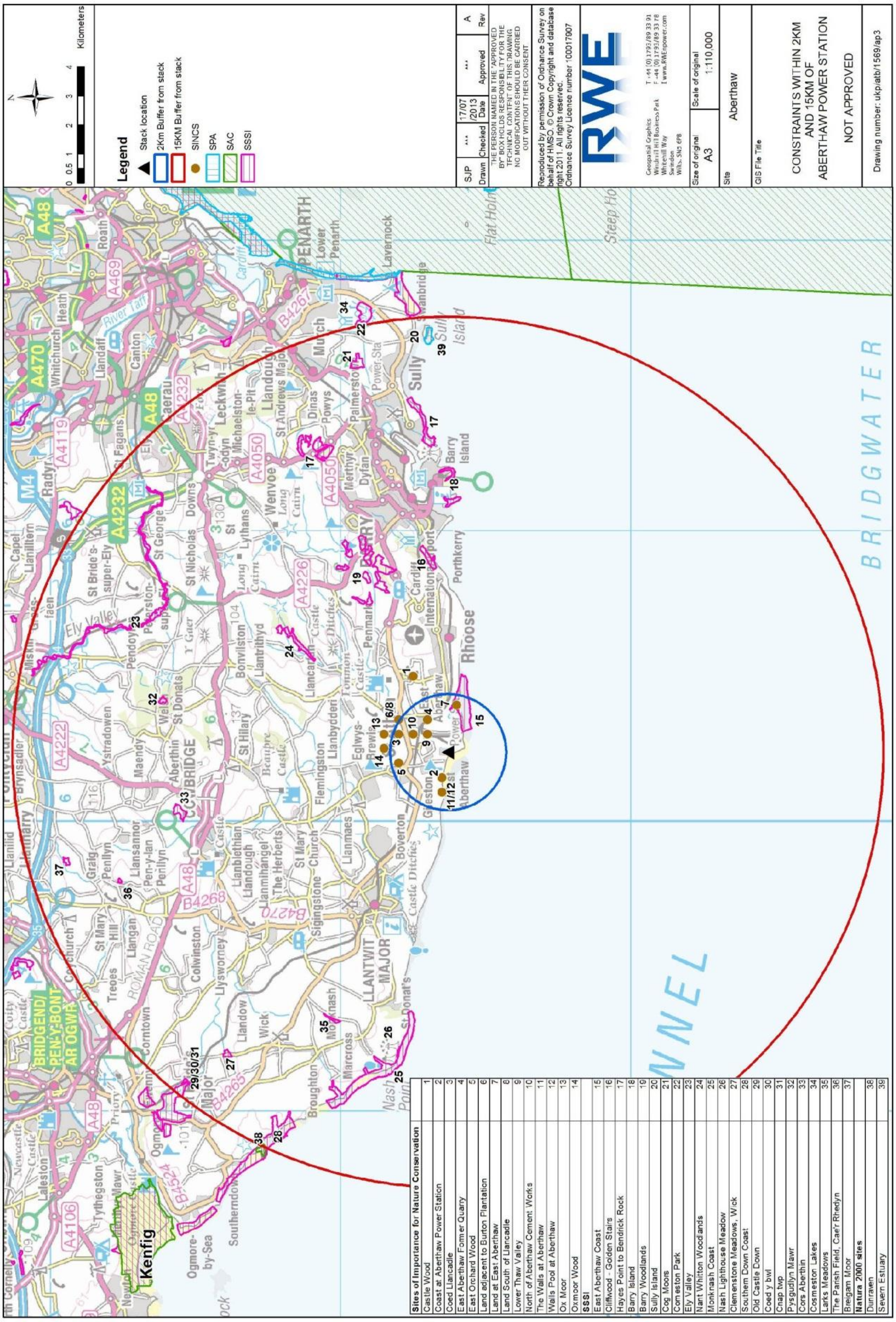

Figure 2: Natura 2000 sites, SSSIs and Local Wildlife Sites (known locally as Sites of Importance for Nature Conservation) near Aberthaw Power Station

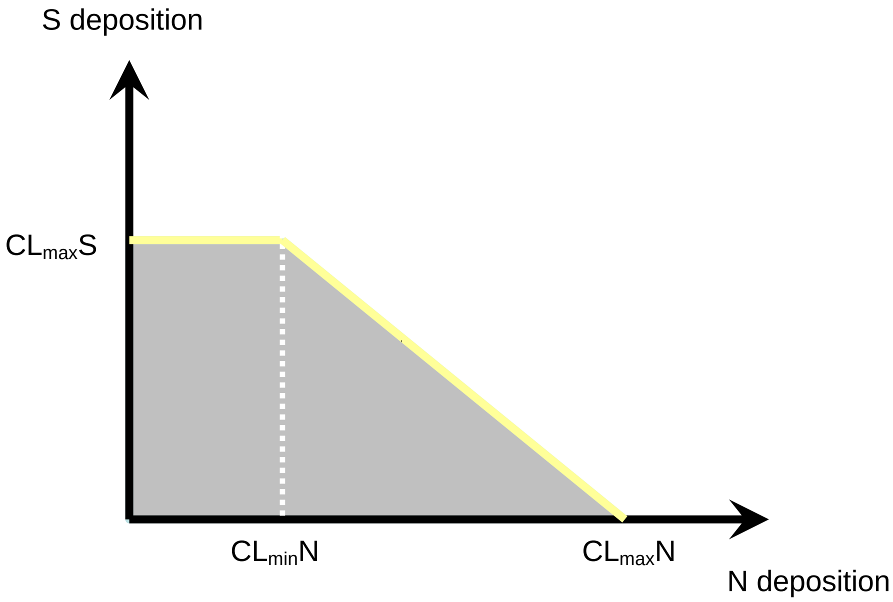

Figure 3: Parameters describing the critical load function for acidity (if the combined sulphur and nitrogen deposition lies within the shaded area, the critical load is not exceeded)

Appendix A. Modelling methodology

A.1. Model application details

ADMS version 5.0.0 (CERC, 2012) has been used for this air quality modelling study. ADMS is a well-established plume dispersion model which has been used extensively for power station emission modelling and has undergone several validation studies (e.g. JEP, 2004). ADMS is the model used for AQS Management Plan purposes at Aberthaw Power Station (as agreed with the Environment Agency/Nature Resources Wales), and the input parameters used in this study are based on those used for AQS Management Plan modelling.

A.2. Emission parameters

Table A1 summarises the emission parameters used in the modelling. The assumed emission concentrations for NO_X, differ in the three modelled scenarios as described in Section 4. The assumed emission concentrations for SO_2, SO_3 and HCl were 350, 20.6 and 2.7 mg/Nm^3 (dry, 6% O_2) respectively as described in Section 4. The oxygen content of the flue gas was assumed to be 6%, and the moisture content 1.1%.

Table A1: Emission parameters

Number of stacks	1
Grid reference of stack	302400,166300
Stack height (m)	152
Effective flue diameter (m)	11.88
Exit temperature (°C)	50
Volume flux at full load per stack (Am^3/s)	1817
Molecular weight (g)	30.5
Specific heat capacity at constant pressure (J/^{o}C/kg)	1023.8
NO_x emission rate for scenario 0 (g/s NO_2-equivalent)	1595
NO_x emission rate for scenario 1 (g/s NO_2-equivalent)	1367
NO_x emission rate for scenario 2 (g/s NO_2-equivalent)	684
% NO_2 in NO_x	1.6
SO_2 emission rate (g/s)	532
SO_3 emission rate (g/s)	31.3
HCl emission rate (g/s)	4.1

A.3. Coastline

As the Aberthaw Power Station stack is within 1km of the Bristol Channel, it may experience some coastal dispersion phenomena. The location of the Met Office observing site at St Athan (about 2.5 km northwest of the power station) ensures that sea breeze events will have been captured appropriately in the meteorological data, including changes in wind direction and near surface air temperature. The ADMS coastline module was not used, as this has not been validated against field data and is not used for AQS Management Plan modelling purposes.

A.4. Topography

Variations in local topography, where there are sustained gradients greater than 1:10, can have a significant effect on the dispersion of emissions. Gradients in the vicinity of Aberthaw Power Station are less than 1:10 over the distance that the plume impact is greatest, and so for modelling purposes the terrain has been assumed to be flat, as for AQS Management Plan modelling.

A.5. Buildings

Large buildings in the vicinity of discharge stacks have the potential to increase ground level concentrations by causing the plume to “downwash” into the building wakes. However, for large coal-fired power stations such as Aberthaw, the stack is sufficiently high that such effects are not significant. Thus, as for AQS Management Plan modelling, building effects were not included in this study.

A.6. Meteorological data and surface roughness

Hourly varying meteorological data have been used in ADMS. These data comprise: wind speed (m/s), wind direction (degrees), near-surface air temperature (^{o}C), cloud cover (oktas), precipitation rate (mm/hour) and near-surface relative humidity (%). The data were obtained from the Met Office monitoring site at St Athan, about 2.5km northwest of the power station. Five years of meteorological data have been used, 2006-2010. As for AQS Management Plan modelling, a roughness length of 0.1 m was used for both the station and Met Office monitoring sites.

A.7. Modelling grid and other receptor points

For impacts on human health and on Sites of Importance for Nature Conservation (SINCs) within 2 km, model runs were performed using a grid with 500m resolution covering an area of 15 km x 15 km around the power station. The grid was centred near the location of the power station stack at OS grid co-ordinates 302500, 166500.

Impacts at Natura 2000 sites and SSSIs within 15 km were modelled at the locations specified in Section 3.1.2.

A.8. NO_X chemistry

The majority of NO_x emitted from Aberthaw Power Station will be in the form of NO, with only about 1.6% (by volume) of NO_X in the form of NO_2 (Section 4). However, NO reacts with ozone in the atmosphere to form NO_2 and, therefore, power stations can contribute to ambient NO_2 concentrations via both "primary" emissions of NO_2 and "secondary" production of NO_2 in the atmosphere.

ADMS contains a NO_X chemistry module which can model the total station contribution to NO_2, taking account of background levels of NO_X, NO_2 and ozone. In this study, the NO_X chemistry module was run using only background ozone concentrations, i.e. background levels of NO_X and NO_2 were ignored. This approach is adequate for current purposes, as previous studies (JEP, 2008) have shown that maximum plume impacts calculated using only ozone agree with results using full chemistry to within ~20%.

As for AQS Management Plan modelling, the ozone data used were those obtained from the UK National Air Quality Archive (http://uk-air.defra.gov.uk/) for Yarner Wood in south Devon. Although this is about 90km south-southwest of the station, the data are representative of rural areas around Aberthaw since ozone is a regional pollutant. If background ozone data from the monitoring sites in the immediate vicinity of Aberthaw Power Station were used, plume impacts could be underestimated, as "background" measurements close to the station may be depleted by reaction with NO from the existing station plume.

A.9. Deposition calculations

Nutrient and acid nitrogen deposition were calculated as the sum of NO_2 and NO dry deposition. Dry nitrogen deposition was calculated from modelled NO_2 and NO concentrations, with concentrations modelled assuming (pessimistically) no plume depletion by dry deposition. The wet deposition of NO_2 and NO is negligible.

Acid deposition due to non-nitrogen species (acid "sulphur" deposition) was calculated as the sum of SO_2, SO_3 and HCl dry deposition plus wet deposition due to SO_3 and HCl. It was assumed that one unit of HCl deposition (keq H^+/ha/year) is equivalent to one unit of sulphur deposition in terms of acidification. Dry deposition was calculated from modelled SO_2, SO_3 and HCl concentrations. SO_3 and HCl wet deposition were modelled directly using the ADMS deposition option. As dry deposition generally dominates SO_2 deposition from the plume close to the source, wet deposition of SO_2 was not included. Any underestimation arising from the exclusion of wet deposition was countered by the use of an upper estimation of the dry deposition velocity for SO_2, as in the deposition modelling for the initial permit application under PPC (JEP, 2006).

The washout coefficients used for SO_3 and HCl wet deposition modelling were the ADMS default vales of 0.0001 s^{-1}(A) and 0.64 s^{-1}(B) (CERC, 2012). The dry deposition velocities used are shown in Table A2.

Table A2: Deposition velocities

Substance	Deposition velocity (m/s)		Reference
	Woodland	Non-woodland	
NO_2	0.003	0.0015	JEP, 2006
NO	0.0003	0.00015	ADMS default*
SO_2	0.024	0.012	JEP, 2006
SO_3 (as sulphate aerosol)	0.002	0.001	Abbott et al, 2003 (FRAME default)*
HCl	0.06	0.025	JEP, 2006

* Single value quoted in the reference for this pollutant species is assigned to low-lying vegetation.

A.10. References

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Appendix B. Acidity critical loads for nature conservation sites

Table B1: Parameters defining critical loads for acid deposition for nature conservation sites local to Aberthaw Power Station (obtained from the UK Air Pollution Information System (APIS))

Nature conservation site	$CL_{max}S$ ($keqH^{+}/ha/year$)	$CL_{min}N$ ($keqH^{+}/ha/year$)	$CL_{max}N$ ($keqH^{+}/ha/year$)
Dunraven Bay SAC		Not sensitive	
Kenfig/Cynffig SAC	0.83	0.223	1.053
Severn Estuary		Not sensitive	
Breigam Moor SSSI		Not sensitive	
Clemenstone Meadows, Wick SSSI	4	0.856	4.856
Cliff Wood – Golden Stairs SSSI	8.342	0.142	8.484
Coed y Bwl SSSI	8.379	0.142	8.521
Coedydd y Barri/Barry Woodlands SSSI	2.525	0.142	2.882
Cog Moors SSSI	4	0.928	4.928
Cors Aberthin SSSI	3.86	0.85	4.72
Cosmeston Park SSSI	2.525	0.214	2.882
East Aberthaw Coast SSSI		Not sensitive	
Ely Valley SSSI		Unknown	
Larks Meadows SSSI	3.84	0.85	4.7
Llynnoedd Cosmeston/Cosmeston Lakes SSSI		Unknown	
Monknash Coast SSSI	4	0.856	4.856
Nant Whitton Woodlands SSSI	2.596	0.142	2.953
Nash Lighthouse Meadow SSSI	4	0.856	4.856
Old Castle Down SSSI	4.07	0.892	4.962
Pysgodlyn Mawr SSSI		Unknown	
Southerndown Coast SSSI	8.333	0.142	8.475
Sully Island SSSI		Not sensitive	
The Parish Field, Cae'r Rhedyn SSSI	3.85	0.85	4.71
Castle Wood SINC*	8.36	0.14	8.5
Coast at Aberthaw Power Station SINC	4.07	1.11	5.18
Coed Llancadle SINC*	8.35	0.14	8.49
East Aberthaw Former Quarry SINC	3.84	0.85	4.7
East Orchard Wood SINC*	8.35	0.14	8.49
Land adjacent to Burton Plantation SINC	3.84	0.85	4.7
Land at East Aberthaw SINC	3.84	0.85	4.7
Land South of Llancadle SINC	4**	Unknown***	4**
Lower Thaw Valley SINC	4**	Unknown***	4**
North of Aberthaw Cement Works SINC	3.84	0.85	4.7
Ox Moor SINC	4**	Unknown***	4**
Oxmoor Wood SINC*	8.35	0.14	8.49
The Walls at Aberthaw SINC	3.84	0.85	4.7
Walls Pool at Aberthaw SINC	4**	Unknown***	4**

* Ancient woodland site as well as SINC.

** Empirical critical load based on dominant soil type, as no habitat-specific critical load available for this coastal habitat type.

*** Value of zero assumed in APIS Critical Load Function Tool.

Appendix C. Background air concentration and deposition rates at nature conservation sites

Table C1: Background sulphur and nitrogen deposition rates at nature conservation sites local to Aberthaw Power Station (obtained from the UK Air Pollution Information System (APIS))

Nature conservation site	Background annual mean NOx concentration (μg/m^3)	Background S deposition (keqH$^+$/ha/year)	Background N deposition (keqH$^+$/ha/year)
Dunraven Bay SAC	7.5	0.14	0.67
Kenfig/Cynffig SAC	9.6	0.14	0.90
Severn Estuary SPA	12.5	0.13	0.75
Bregam Moor SSSI	10.7	0.17	1.23
Clemenstone Meadows, Wick SSSI	8.0	0.15	1.14
Cliff Wood - Golden Stairs SSSI	11.3	0.16*	1.63*
Coed y Bwl SSSI	13.3	0.19*	2.02*
Coedydd y Barri/Barry Woodlands SSSI	11.3	0.16*	1.63*
Cog Moors SSSI	12.5	0.13	0.75
Cors Aberthin SSSI	11.0	0.17	1.14
Cosmeston Park SSSI	12.5	0.15*	1.38*
East Aberthaw Coast SSSI	9.2	0.13	0.97
Ely Valley SSSI	15.0	0.19*	2.02*
Larks Meadows	8.0	0.15	1.14
Llynnoedd Cosmeston/Cosmeston Lakes SSSI	12.5	0.13	0.75
Monknash Coast SSSI	6.9	0.13	0.69
Nant Whitton Woodlands SSSI	11.1	0.18*	1.99*
Nash Lighthouse Meadow SSSI	6.9	0.13	0.69
Old Castle Down SSSI	13.3	0.16	1.14
Pysgodlyn Mawr SSSI	11.0	0.17	1.14
Southerndown Coast SSSI	7.5	0.17*	1.22*
Sully Island SSSI	12.5	0.13	0.75
The Parish Field, Cae'r Rhedyn SSSI	10.7	0.17	1.23
Castle Wood SINC**	11.3	0.16*	1.63*
Coast at Aberthaw Power Station SINC	9.1	0.13	0.97
Coed Llancadle SINC**	9.1	0.16*	1.78*
East Aberthaw Former Quarry SINC	9.2	0.13	0.97
East Orchard Wood SINC**	9.1	0.16*	1.78*
Land adjacent to Burton Plantation SINC	9.2	0.13	0.97
Land at East Aberthaw SINC	9.2	0.13	0.97
Land South of Llancadle SINC	9.2	0.13	0.97
Lower Thaw Valley SINC	9.2	0.13	0.97
North of Aberthaw Cement Works SINC	9.1	0.13	0.97
Ox Moor SINC	9.1	0.13	0.97
Oxmoor Wood SINC	9.2	0.16*	1.78*
The Walls at Aberthaw SINC	9.2	0.13	0.97
Walls Pool at Aberthaw SINC	9.2	0.13	0.97

* Deposition rate for woodland habitat. Values at all other sites assume low-lying vegetation.

** Ancient woodland site as well as SINC.

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Appendix B. Supplier Technical Documents

Application of Foster Wheeler Ultra-Low NOx Combustion Technology on Nghi Son Arch Fired Boilers in Vietnam

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Presented at
Power-Gen Asia 2011
KLCC, Kuala Lumpur
Malaysia
27 – 29 September 2011

Application of Foster Wheeler Ultra-Low NOx Combustion Technology on Nghi Son Arch Fired Boilers in Vietnam

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Beijing, P.R. China

Abstract

Nghi Son power plant project is in Vietnam electricity development plan period 2001-2010 (forecast to 2020) to meet load development demand in Nam Thanh – Bac Nghe area and to reduce transmission loss in national power system. Nghi Son (1) power plant project with installed capacity of 2 x 300 MW coal fired generating units will be constructed in Nghi Son economic zone, Tinh Gia district, Thanh Hoa province, Central North of Vietnam. The boiler shall burn Vietnamese anthracite coal only

Combustion equipment design for firing low volatile coals is a very challenging task due to the difficulty of maintaining stable combustion and at the same time keeping the low NOx emissions. Higher combustion temperature favors stable combustion of low volatile fuels however it also creates higher thermal NOx. The low content of volatile matter makes it very difficult to design a combustion system to effectively control the NOx emissions at lower level.

Foster Wheeler (FW) conducted a comprehensive R&D program in the late 1990s for arch-fired burner firing low volatile anthracite. It included a series of tests with a range of anthracite coals firing a single 75 MMBTU/hr burner installation. Combustion tests were conducted at this FW's 22MW$_{th}$ Test Facility. It has been successfully applied to several power plants using arch-fired boilers. Up to date, FW is the only company capable of guaranteeing lower NOx emission level for firing low volatile coals. Generally, with OFA (Over Fire Air) the guaranteed and easily met NO_x emission was 510 mg/Nm^3 at 6% O_2 dry. To date, the operation results of the arch-fired boilers using FW low NOx burners shown consistent lower NOx emissions. This paper updates the application of FW Advanced low NOx burners to arch-fired boilers.

Introduction

As NOx regulations become ever more restrictive, each individual combination of burner design and coal type must be analyzed to employ the proper technology to reduce NOx emissions. Foster Wheeler (FW) has proven Low NOx burner technologies available for Arch Firing of low volatile fuels. The design of new boilers and the application of these technologies in retrofits are presented in combination with the effects of different coal types. The paper presents the fundamental theories underlying NOx generation and reduction, followed by burner design concepts and performance results from actual operations.

NOx Formation

With the steady increase in combustion of hydrocarbon fuels, the products of combustion are distinctly identified as a severe source of environmental damage. Nitrogen oxides (NOx) are one of the primary pollutants emitted during combustion processes. Along with sulfur oxides (SOx) and particulate matter, NOx emissions have been identified as contributors to acid rain and ozone formation, visibility degradation and human health concerns. NOx refers to the cumulative emissions of nitric oxide (NO), nitrogen dioxide (NO_2) and trace quantities of other species generated from combustion. Combustion of any fossil fuel generates some level of NOx due to high temperatures and the availability of oxygen and nitrogen from both the air and fuel.

NOx emissions from fired processes are typically more than 90% NO, 5 to 10% NO_2 and about 1% N_2O. However, once the flue gas leaves the stack, the bulk of the NO is eventually oxidized in the atmosphere to NO_2. It is the NO_2 in the flue gas which creates the brownish plume often seen in a power plant stack discharge. Once in the atmosphere, the NO_2 is involved in a series of reactions which form secondary pollutants. The NO_2 can react with sunlight and hydrocarbon radicals to produce photochemical (urban) smog and acid rain constituents. [2]

Four different routes are now identified in the formation of NOx. These are the thermal route, the prompt route, the N_2O route, and the fuel-bound nitrogen route. [3][4]

Thermal NOx or Zeldovich NOx is formed by the elementary reactions:

$$O + N2 \rightarrow NO + N \quad (1)$$

$$N + O2 \rightarrow NO + O \quad (2)$$

$$N + OH \rightarrow NO + H \quad (3)$$

The name “thermal” is used, because the Reaction (1) has very high activation energy due to the strong triple bond in the N_2 molecule, and is thus sufficiently fast only at high temperatures. The traditional factors leading to complete combustion (high temperature, long residence time, and high turbulence or mixing) all tend to increase the rate of thermal NOx formation. Therefore, some compromise between effective combustion and controlled NOx formation is needed.

The amount of NOx formed by thermal route is strongly dependent on temperature and increases exponentially at temperatures above 1200°C. Reduction of the thermal NOx can be accomplished through a number of combustion system modifications. Controlled mixing burners can be used to reduce the turbulence in the near burner region of the flame and to slow the combustion process. This typically reduces the flame temperature by removing additional energy from the flame before the highest temperature is reached. Another approach is staged combustion where only part of the combustion air is initially added to burn the fuel. The fuel is only partially oxidized and then cooled before the remaining air is added separately to complete the combustion process. A third alternative is to mix some of the flue gas with the combustion air at the burner, referred to as flue gas recirculation. This increases the gas weight which must be heated by the chemical energy in the fuel, thereby reducing the flame temperature. These technologies have been used effectively with gas, oil and coal firing to reduce NOx formation. For fuels which do not contain significant amounts of chemically bound nitrogen, such as natural gas, thermal NOx is the primary overall contributor to NOx emissions.

Prompt or Fenimore NOx is formed by reactions between nitrogen from air and hydrocarbon radicals such as CH and HCN. The amount of prompt NOx is small compared to thermal NOx.

The conversion of fuel-bound nitrogen into NOx is mainly observed in coal combustion. Usually the nitrogen content in coal is 0.5% to 2.5%. The nitrogen containing compounds evaporate during the gasification process and lead to NO formation in the gas phase. Fuel-bound nitrogen contributes to about 75% to 90% of NOx emission when firing coal. The mechanism of fuel-bound nitrogen NOx formation is very complicated and researchers are still working on it now. However, the research results show that there are basically two separate paths for the conversion of fuel-bound nitrogen into NOx for coal combustion. The first path involves the oxidation of nitrogen released from the coal devolatilization process. During the initial phase of coal combustion, nitrogen reacts to form several intermediate compounds in the fuel rich flame region. These intermediate compounds are then either oxidized to NO or reduced to N_2 in the post-combustion zone. The formation of either NO or N_2 is strongly dependent on the local fuel/air stoichiometric ratio. This volatile release mechanism is estimated to account for 60% to 80% of the fuel NOx contribution. [2]

Arch Fired Burners for Firing Anthracite

The double arch down-fired or W flame furnace is the proven way to efficiently self-combust anthracites in central station steam generators. About 2/3^{rds} capacity of the world's units ordered or in service firing low volatile pulverized coals are FW-design AF (Arch Firing) units, totaling some 28,000 MW_e. Figure 1 shows the typical FW AF furnace arch and vertical "air" wall arrangement, having individually-controlled cyclone burners and multiple air compartments in each burner. The FW AF technology retains the same high (~70/30) flow rate ratios of vertical-wall-air/ arch-air of the early vertically-fired systems, maximizing the effect on ignition by the entrainment of up-flowing hot gases into the arch. Together with the cyclone burners' enrichment of the fuel/air mixture discharged through the burner nozzle, the above-mentioned flow rate ratios make it possible to fire anthracite coal with only 1.5% hydrogen without support fuel at full load. Also, NO_x emissions are lower than those of competing AF technologies.

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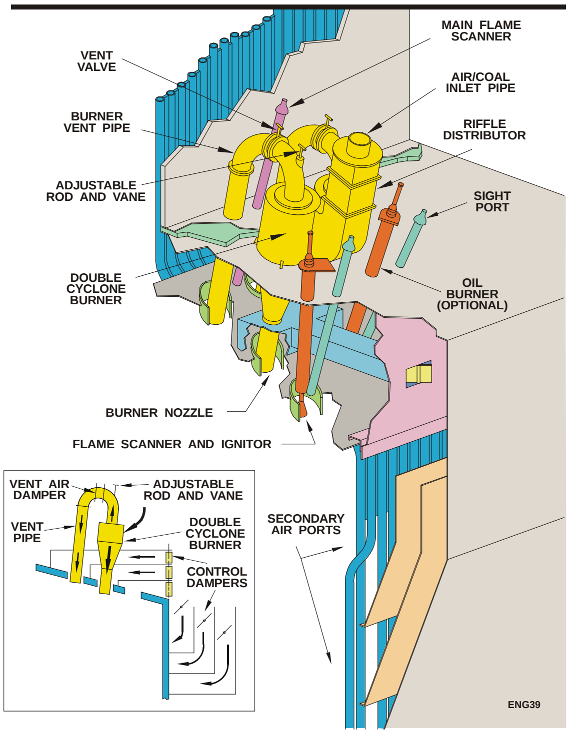
FIGURE 1: Classic FW AF System



To enable the FW AF technology to fire fuels with lower ranges of volatile matter and produce lower levels of NO_x emissions, a comprehensive R&D program was undertaken in the late 1990s. The outcome of this program resulted a modified arch-fired burner firing anthracite and produce lower levels of NOx emissions. Figure 2 illustrated the modification of an existing FW AF burner nozzle design into a Fuel Preheat Nozzle. This FW-proprietary modification involves shortening the fuel nozzle and substituting a hollow cylinder ("core") for the rod that supports the standard flow-straightening vanes. This modification allows for increased venting of cold primary air, while maintaining the velocity for proper penetration of the flame. This design also favors the mixing of the cooler coal with the surrounding hot arch ("tertiary") air before it reaches the furnace, because the remaining passage is narrower.

Besides enhancing ignition, the fuel preheat results in char formation (coking, or gasifying by pyrolysis) at higher temperatures that yield more volatiles (increased gasification efficiency). This is favorable to lower NOx when there is air staging at the burner level, as in the classic FW AF technology.

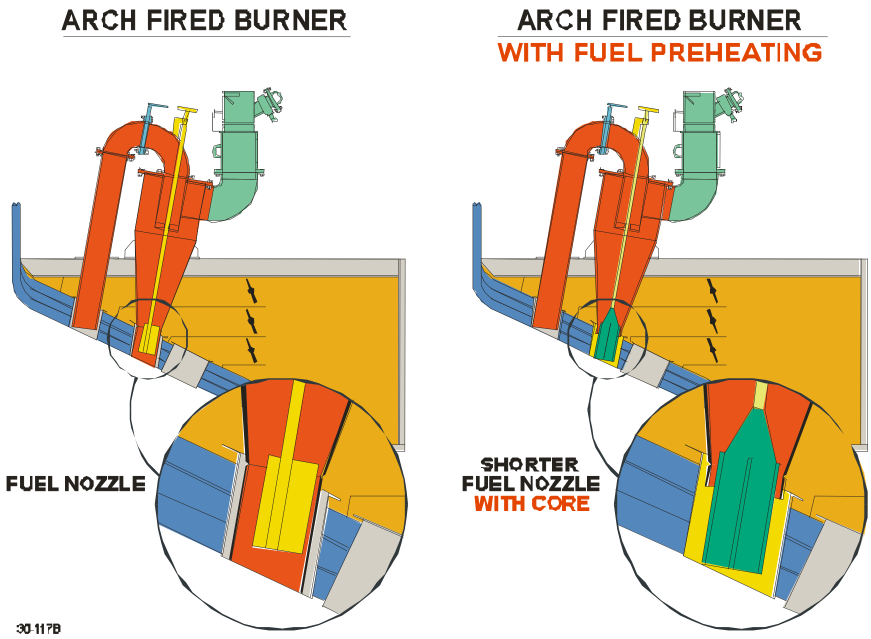


FIGURE 2: Comparison of Classic and Fuel Preheat FW AF Burners

Figure 3 is a view of an additional air stage, discharging above the arch, consisting of one opening per burner with two concentric ports, called "peripheral" and "central". The latter integrates the FW proprietary vent-to-OFA arrangement [6]. The coal/air conduits are not shown in the figure, for the sake of clarity.

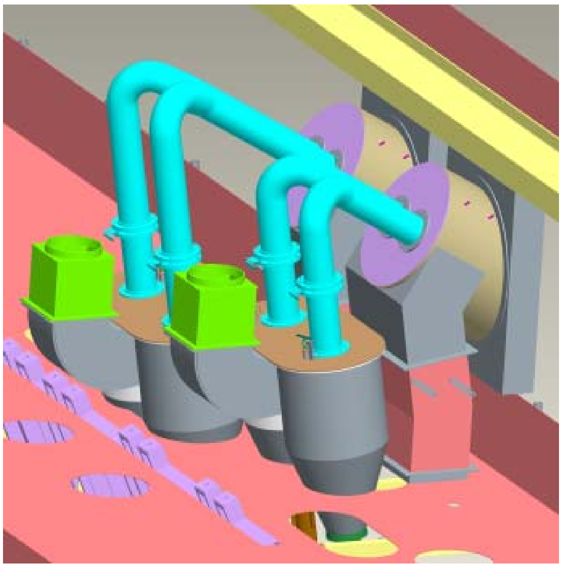


FIGURE 3: FW Double Cyclone Burners with Vent-to-OFA

Relative to the central port, the peripheral port is designed for low flow and high velocity, increased by swirling vanes, and is to be used preferentially at comparatively low OFA flows. Thus, within a broad range of OFA flows the OFA jet can achieve similar penetration in the furnace depth and can suction all of the up-flowing gases. The vent conveys most of the coal moisture and the finest and hence fast-burning fraction of the pulverized coal in a very lean phase, made even leaner by the central OFA. These OFA, moisture and finest coal mix with gases already depleted of oxygen by the burning in the lower furnace.

The standard nozzle modification into a Fuel Preheat Nozzle (Figure 2) allowed the coal such as the 5% volatiles, 1% hydrogen anthracite to be fired, without support fuel and at half load of the boiler, mill and burner. In fact, the temperature of the coal/air mixture entering the furnace could exceed 400^{o}F (205^{o}C)[7]. This is well within the range reached by indirect firing systems, which usually require one extra bay in the plant and a multitude of additional equipment to operate and maintain. The conclusion is that the preheating accomplished by the Fuel Preheat Nozzle is equivalent to the preheating achieved by indirect firing, with significantly lower capital and O&M costs.

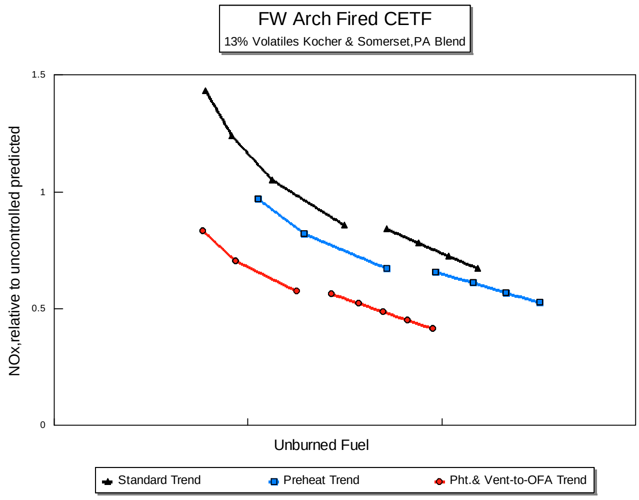


FIGURE 4: Relative NO_x vs. Unburned Fuel

Each successive modification resulted in further reduction of NO_x at a given stoichiometry (air ratio) in the lower furnace. Figure 4 shows, for the coal blend, the relative NO_x as a function of unburned fuel. For a given NO_x, the corresponding unburned fuel was reduced by each modification. With the fuel preheat and vent-to-OFA modifications, over 50% reduction of NO_x resulted in a less than doubling the unburned fuel. Trends were similar with the other fuels, particularly for the right-hand curves that correspond to operation with OFA.

In response to a U.S. Environmental Protection Agency's Pennsylvania State Implementation Plan (EPA SIP) the contractual objective of the Sunbury, USA Units 1 and 2 retrofits in 2002 was to reduce the NO_x by more than 50% to 0.43 lb/10^6 BTU (~510 mg/Nm^3).

Table 1 shows analysis of the coals of the baseline testing and of the low NO_x testing coal that is also currently being burned at Sunbury 1 & 2. Both coals are local and include low-quality anthracites, rejects from past coal cleaning operations.

TABLE 1: Sunbury 1 & 2 Coals Analysis (As Received Basis, ASTM Analysis)

	Analysis, % by weight							HHV[c]	HGI[d]
Coals	**VM[a]**	Ash[a]	H_2O[a]	C[b]	**H[b]**	N[b]	S[b]	Btu/lb (kcal/kg)	
Baseline Tests Silt & Buck (semi-anthracite)	**7.58**	33	13.87	48.16	**1.26**	0.62	0.53	7,504 (4,170)	63
Low NO_x Tests Silt (anthracite)	**6.71**	31.71	15.67	48.27	**1.43**	0.63	0.53	7,598 (4,220)	71

a) Proximate Analysis: Volatile Matter (VM) Ash and total moisture (H_2O)
b) Ultimate Analysis: elements as shown
c) Higher Heating Value
d) Hardgrove Grindability Index

The Sunbury units 1 and 2 each has two boilers. Each boiler has about 50 MW_e capacity, two FW ball mills and twelve burners. The furnaces of the Sunbury Units 1 and 2 were modified by the addition of:

- A conventional boundary air system to counteract potential slagging of the lower furnace even under the sub-stoichiometric conditions conducive to lower NO_x.
- The Fuel Preheat Nozzle modification to FW Double-cyclone Arch Burners, as per Figure 6.
- An additional air stage, discharging above the arch consisting of one opening per burner with two concentric ports integrating the Vent-to-OFA in an arrangement functionally equivalent to that shown in Figure 7.

Figure 5 is a plot of NO_x at the AF CETF (FW Combustion and Environmental Test Facility) and from Sunbury 1 & 2 tests, versus lower furnace stoichiometry (air ratio). This is explained next. “Screening” tests at the AF CETF were in accordance with the design-of-experiments (DOE) method. A practical application of the DOE method [8] was used to analyze “effects (of air damper settings) and interactions” on the results, except for applying sets theory (Boolean algebra) so that two factors that are “negative” from the NO_x reduction standpoint cannot become “positive” when jointly applied. The conclusion was that, except for settings conducive to unacceptable unburned or conversely to very high NO_x, the key parameter for the FW AF designs is the stoichiometry (air ratio) in the lower furnace. This stoichiometry coincides with the final or furnace exit stoichiometry in cases without OFA (right hand side straight line in

Figure 5, also valid for all units of classic FW AF design and operation). As seen here, Sunbury 1 & 2 NO_x reduction improved relative to the AF CETF [9].

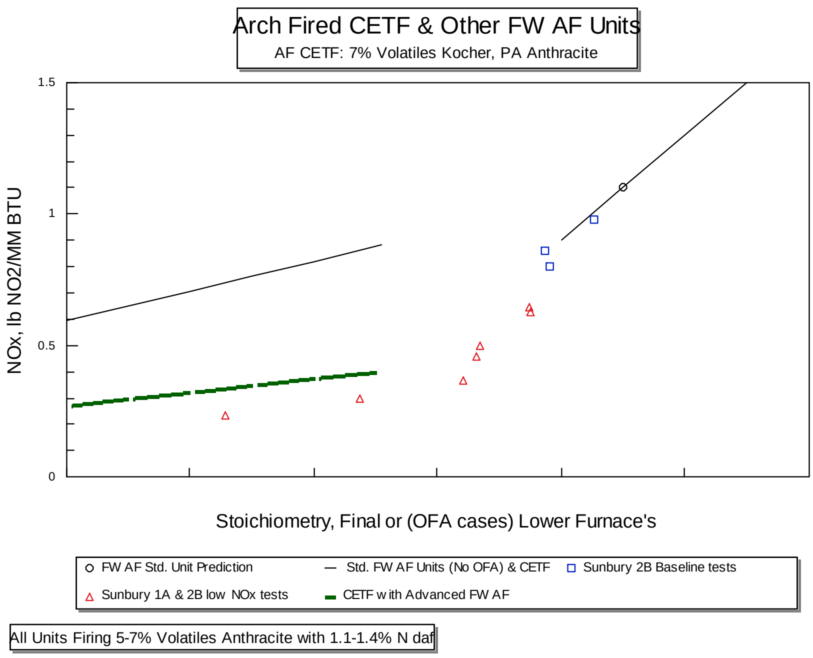


FIGURE 5: NO_x vs. Lower Furnace Stoichiometry (Air Ratio)

Consistent operation with Sunbury's typical low-quality 7% volatiles anthracite has been on occasions at 0.2 lb/10^6 BTU (~250 mg/Nm^3). The CO emission guarantee of 100 ppmv was amply met, helped by improved air and gas mixing as indicated by the more even O_2 readings when OFA is in service [9]. Final steam de-superheating, before and after the retrofit of the advanced FW AF, are similar. As an illustration of the fuel flexibility of the advanced FW AF technology, Figure 6 shows consecutive hourly NO_x data from Sunbury 2 while firing a low-volatile (18% VM) bituminous coal. Although no attempt was made to minimize NO_x, the average of this period was 0.17 lb/10^6 BTU (~200 mg/Nm^3). The unburned in flyash was markedly lower than with anthracite.

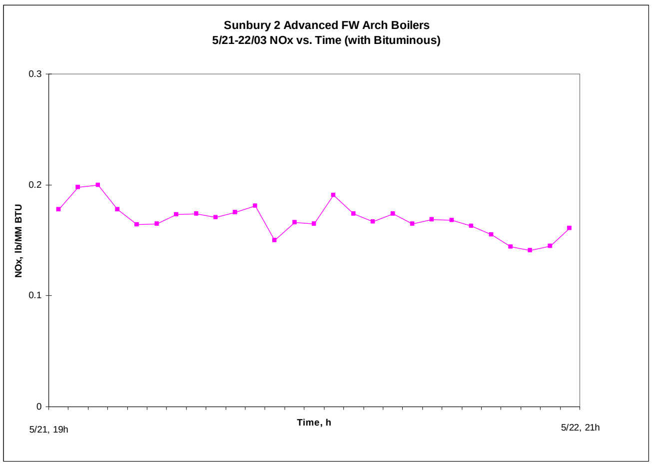


FIGURE 6: Hourly NO_x with 18% Volatiles Coal

Answering to regulations by the Republic of Korea [10], the contractual objective of the Seocheon, Korea Units 1 and 2 retrofits, in 2005 and 2004 respectively, was to reduce the NO_x by some 50% to 250 ppmv at 6% O_2 dry, equivalent to ~0.43 lb/10^6 BTU (~510 mg/Nm^3). Table 2's analysis of the contractual coal for the retrofit proved representative of the coal available during retrofit commissioning and testing.

The 2 x 200 MW_e Seocheon, Korea Units 1 and 2 were designed by other OEM, therefore:

- It has an indirect firing system, which includes PC cyclones and PC bag filter collectors as can be seen in grey color on the top of Figure 7. PC bins and PC feeders, not shown in the figure, are just underneath the PC cyclones.
- It provided only ~10% of the combustion air through the vertical walls. The front vertical wall supply ducts and plenum are also shown in gray color about 1/3rd of the way up on the boiler in Figure 7.
- The boiler (water-steam) system, including the furnace walls that were to be modified with OFA openings, has pump-assisted circulation.
- It had no PC separating capability upstream of the 2 x 20 burner nozzles, which each discharged through a slot.

TABLE 2: Seocheon Retrofit Contractual Coal Analysis (As Received Basis)

	Analysis, % by weight							HHV[c]	HGI[d]
Coals	**VM[a]**	Ash[a]	H_2O[a]	C[b]	**H[b]**	N[b]	S[b]	Btu/lb (kcal/kg)	
Korean Anthracite	**4.42**	30.35	9.14	57.47	**1.02**	0.35	0.38	8,670 (4,817)	70

a) Proximate Analysis: Volatile Matter (VM) Ash and total moisture (H_2O)

b) Ultimate Analysis: elements as shown

c) Higher Heating Value

d) Hardgrove Grindability Index

As shown by Figure 7 in light-green color, from top to bottom these were the main additions or modifications supplied and/or designed by FW:

- 18 OFA ports were placed above the arch.
- 2 x 18 FW cyclones were added above the arches and each with the round-discharge fuel preheat nozzle fitting in the pre-existing slot. Each coal discharge slot originally next to a corner was blocked, to respect the standard FW burner-to-side wall clearance.
- OFA supply ducts and a plenum were located on each arch next to the upper front or rear wall.
- New air wall ("tertiary" as per OEM) air supply ducts and plenum were provided for each arch in-between the pre-existing arch air and air wall plenums.
- New air wall openings (not seen in the figure) were made, below each arch and spanning the height of the corresponding new "tertiary" plenum shown in the figure.

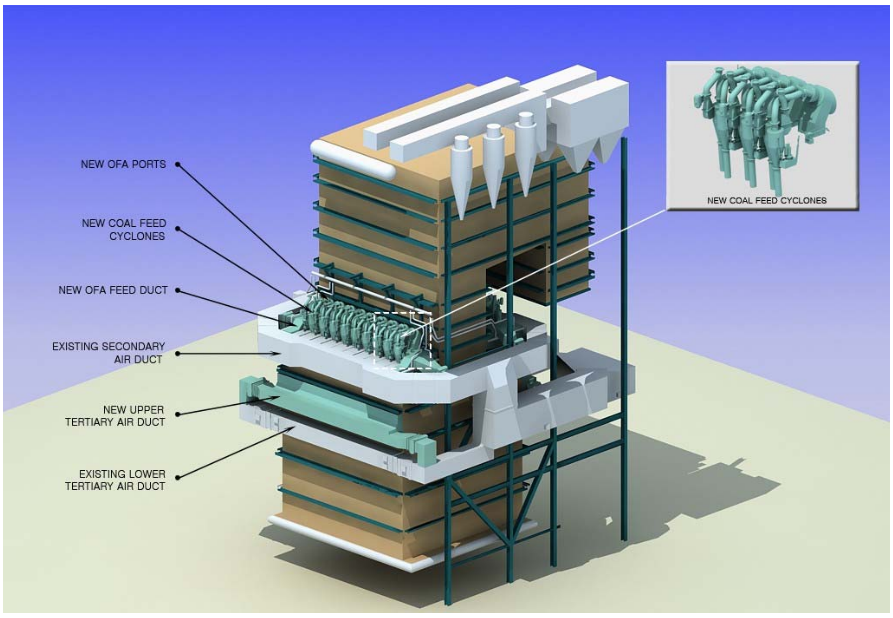


FIGURE 7: Seocheon Boiler Perspective View

Figure 8 is a plot of coal-generated NO_x versus lower furnace stoichiometry (air ratio) including the prediction for Seocheon based on Sunbury 1 & 2, the baseline test and the post-retrofit tests results. The guaranteed NO_x of 0.43 lb/10^6 BTU (~510 mg/Nm^3) was met.
For commercial reasons, the customer operates at MCR with 20% heat input from fuel oil. According to USA EPA data from the then fuel oil-fired Delaware City Refinery Unit 4 - a FW AF boiler previously firing petcoke and nowadays clean gas as per local environmental requirements, the average NO_x was 0.2 lb/MM BTU. Seocheon oil guns discharge in parallel with the adjacent coal nozzles, currently exhibiting very narrow and long flames, the same as the coal flames, which results in limited mixing. During these tests, few oil guns were in service. Furthermore, in Seocheon the supply of air to the air walls was and remains common for all the burners of an arch. Therefore, since oil burns far faster than coal, the oil combustion was generally complete in the lower furnace, as in mentioned Delaware City boiler, which has no OFA. Consequently, one may expect at Seocheon the NO_x from oil to have been ~0.2 lb/MM BTU, hence the ~20% oil input to have contributed ~0.2 x 0.2 = 0.04 lb/MM BTU. In Figure 12 any actual test NO_x that exceeded 0.2 lb/MM BTU has been corrected slightly upwards to "coal-generated NO_x" as follows:

Coal-generated NO_x = (Actual NO_x – 0.04) / 0.8

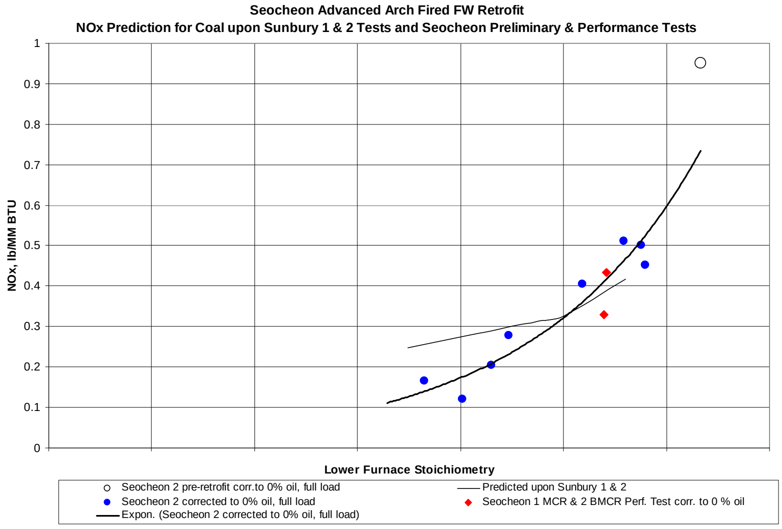


FIGURE 8: NO_x vs. Lower Furnace Stoichiometry (Air Ratio)

Other guarantees met covered the unburned fuel loss as well as CO and de-superheating spray flows, which were similar to the respective pre-retrofit values.

Conclusions

As NOx regulations become ever more restrictive, each individual combination of burner design and coal type must be analyzed to employ the proper technology to reduce NOx emissions. Comparing to the after-combustion treatment technologies such as SCR and SNCR, using combustion modification to reduce NOx formation in the first place has the advantage of lower initial investment and lower operating cost. Foster Wheeler has proven Low NOx burner technologies available for Arch Firing of low volatile fuels.

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Ultra-Low NO_x Advanced FW Arch Firing: Central Power Station Applications

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Ultra-low NO_x Advanced FW Arch Firing: Central Power Station Applications

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ABSTRACT
A total nearing 28,000 MW_e, or about 2/3^{rds} of the world's central station boiler capacity ordered or already operating with low volatile pulverized coal, are Foster Wheeler (FW)-designed arch firing (AF) units. These units are also known as vertically/down-fired or W-fired units. The successful FW AF technology has kept the same high (~70/30) flow rate ratios of vertical-wall-air / arch-air of the early vertically fired systems. Its uncontrolled NO_x emission approaches 1300 mg/Nm^3 at 6% O2 dry or 40% excess air (~1.1 lb/10^6 BTU) for solid fuels with less than 10% volatile matter, or 650 mg/Nm^3 (~0.55 lb/10^6 BTU) for other solid fuels.

When firing higher volatile coals, these classic FW AF units attain NO_x emissions at the low level of the most advanced low-NO_x horizontally-fired burners. However, with low volatile coals, just the addition of over-fire air (OFA) above the arch may achieve only a 20% NO_x reduction relative to its uncontrolled value.

To extend the FW AF technology to lower ranges of fuel volatile matter and lower levels of NO_x emissions, a comprehensive R&D program was undertaken in the late 1990s. It included a series of tests with a range of anthracite coals firing a single 75 MM BTU/h burner installation. Combustion tests were conducted at this FW's 22MW_{th} test facility. This paper updates the application of the Advanced FW AF technology to central power station units.

The identity, retrofit timing and purpose for each of these AF units are:

- 154 MW_e Narcea, Spain Unit 2, partial (no OFA) retrofit of two burners in 2001, successfully furthering flame stability with 5% volatiles, 1% hydrogen coal.
- 4 x 50 MW_e boilers of Sunbury, USA Units 1 and 2, retrofits in 2002 of the Advanced FW AF technology (12 burners per boiler) to reduce NO_x.
- 2 x 200 MW_e Seocheon, Korea Units 1 and 2, of another original equipment manufacturer (OEM), retrofits in 2004 and 2005 of the Advanced FW AF technology (20 burners per unit) to reduce NO_x.
- 350 MW_e Compostilla, Spain Unit 4 partial boiler (6 burners) retrofit, completed in 2005, of the Advanced FW AF technology to reduce NO_x.

Generally, with OFA, the guaranteed and easily met NO_x emission was 0.43 lb/10^6 BTU (~510 mg/Nm^3 at 6% O2 dry). To date, lower consistent NO_x operation of Advanced FW AF technology full retrofits has been at 0.2 lb/10^6 BTU (~250 mg/Nm^3) with anthracite coal, and 0.17 lb/10^6 BTU (~200 mg/Nm^3) with low volatile bituminous coal.

As a result of a substantial NO_x reduction, the Advanced FW AF technology design increases the unburned fuel. The increase in unburned fuel is approximately the same, in proportion, as the increase resulting from low-NO_x horizontally fired burner retrofits. The increase in unburned fuel can be counteracted by retrofitting more efficient classifiers to the mills, like the new adjustable-static classifier for ball mills already installed in the 6 mills of the 330 MW_e Compostilla, Spain Unit 3. The carbon monoxide emissions and the overall furnace thermal performance, before and after the retrofit of the Advanced FW AF technology, are similar.

1. INTRODUCTION

An example of a FW AF unit is shown in Figure 1. This figure shows one of the two 717 MW_e FW AF Hanfeng Boilers[1]. This unit's combustion system consist of six horizontal-drum FW ball mills, shown on the bottom left of the figure. These mills directly feed 36 burners located on two arches, one at the front and another at the rear of the furnace, as seen in the center of the figure. W-shaped flames are formed in the volume of the furnace located below the arch (known as the lower furnace) allowing for; staged air admission that is needed to avoid quenching the slow-burning fuel, for increased (3-4 seconds) residence time of the fuel in the furnace and for entrainment of up-flowing hot gases into the arch to assist the ignition[2]. The upper furnace and ensuing heat recovery area are FW's conventional pulverized coal unit design, including parallel gas passes for reheat steam temperature control.

FIGURE. 1: 717 MW_e Double-Arch Fired Boiler

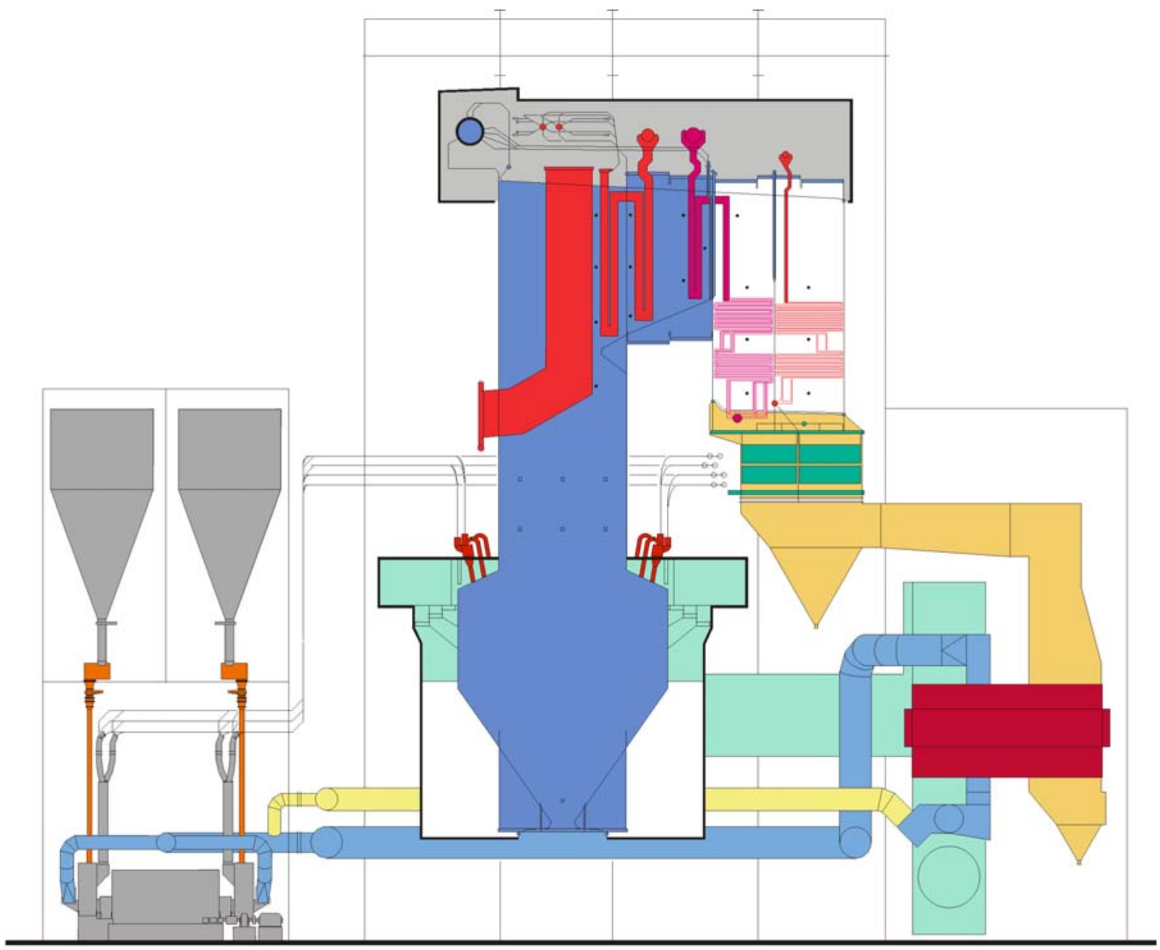
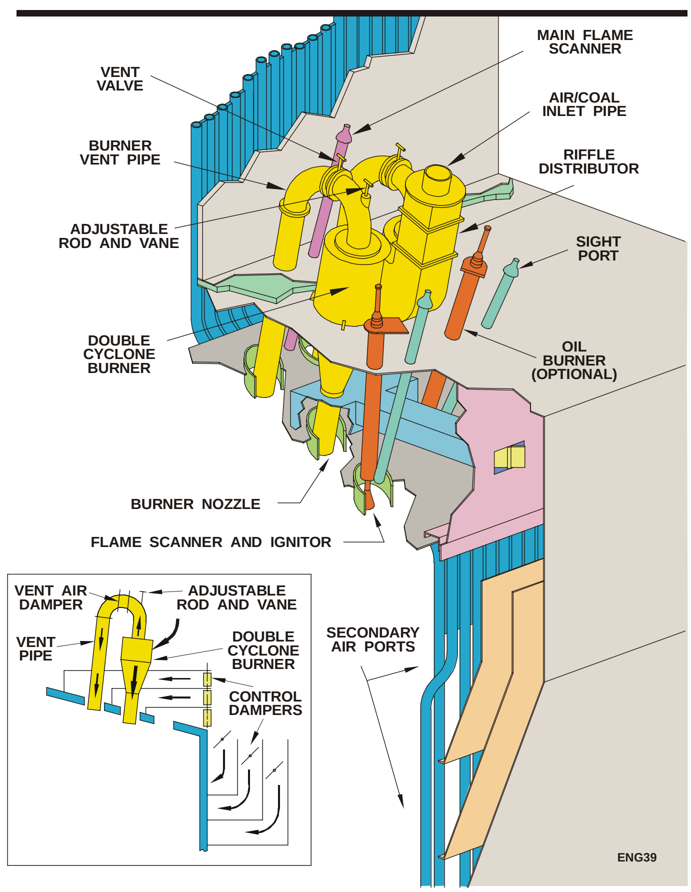


Figure 2 shows the typical FW AF furnace arch and vertical "air" wall arrangement, having individually controlled cyclone burners and multiple air compartments in each burner. The Advanced FW AF technology is designed to retain the same high (~70/30) flow rate ratios of vertical-wall-air / arch-air of the early vertically-fired systems, maximizing the effect on ignition by the entrainment of up-flowing hot gases into the arch.

Together with the cyclone burners enrichment of the fuel/air mixture discharged through the burner nozzle, the above-mentioned air flow rate ratio make it possible to fire anthracite coal with only 1.5% hydrogen without support fuel at full load. Also, NO_x emissions are lower than those of competing AF technologies. The FW AF units' uncontrolled NO_x emissions approach the 1988 European Union Directive limits for new units. These limits were 1300 mg/Nm^3 at 6% O2 dry (~1.1 $lb/10^6$ BTU) for solid fuels with less than 10% volatile matter, and 650 mg/Nm^3 (~0.55 $lb/10^6$ BTU) for other solid fuels.

FIGURE 2: Classic FW AF System



Of the units in service or ordered firing low volatile pulverized coals, approximately 2/3rds of the world's capacity are FW-design AF units, totaling some 28,000 MW_e.

Table 1, on differences among AF technologies, explains the FW AF advantages.

TABLE 1: AF Designs Comparison[3, 4, 5, 6]

Company	**FW**	**A**	**B**
Burner Type Burner Discharge	Separating Round	Slot	Slot
Firing Type	Direct	Indirect	Direct
Minimum* Volatiles, %	4	9.3	11
Minimum* Hydrogen, %	1.8	2.2	2.8
Reported NO_x, mg/Nm3 (< / > 10% Volatiles)	<1300 / <650	1650	1490
~Vertical wall air, %	70	10	0

* NOTE: content required for 40-50% boiler load operation without support fuel.

Additional explanations are.

- The air pressure required to attain the air discharge velocity limits its value, regardless of design. Since the penetration of a jet is also directly proportional to the diameter or, if rectangular, the equivalent diameter of the discharge, the very narrow slots common to OEMs other than FW limit the penetration of the jet-flame in the lower furnace, thus decreasing utilization of the furnace volume and cooling surface.
- Direct-firing systems transport the coal pneumatically to the burners with the mill fluid, normally primary air already cooled by the drying of the fuel in the mill. Indirect-firing systems have, usually located in a devoted additional plant bay, cyclones and/or other separators that collect the solid fuel leaving the mills, intermediate pulverized coal (PC) bins for storage and PC feeders to PC lines that use hot primary air as fluid for pneumatic transport of the coal to the burners. For safe handling of the PC, the indirect system requires coals, or each individual component of a coal blend, that have less than ~12% volatiles.
- Hydrogen content is more representative of the ignitability of a solid fuel than volatile content[2].

In spite of the classic FW AF technology's ignition and NO_x emissions advantages, there are incentives for its improvement. Hard-to-burn coals have been assigned to power generation in China[7] to allow for higher volatile coals to be used for other purposes. However, in some cases it had not been possible to apply arch firing without blending other coals higher in volatile matter with the designated anthracite. These cases are undermining the infrastructure-wise Chinese policy of "Coal by Wire"[8].

Relative to NO_x, China's Emissions Standards effective in 2004[9] include for new units NO_x limits of 1100 mg/Nm^3 at 40% excess air or ~6% O_2 dry (~0.93 lb/MM BTU) for coals with less than 10% volatiles (on dry, ash-free basis, that is <~7% volatiles as received) and, for coals with 10 to 20% volatiles, 650 mg/Nm^3 (~0.55 lb/MM BTU), previously unattainable with anthracite by AF combustion modifications. Also, regulations by the Republic of Korea[10] and the 2001 European Union's Large Combustion Plants Directive[11] (LCPD) impose new NO_x limits on existing units, including some equivalent to 0.43 lb/10^6 BTU (~510 mg/Nm^3 or ~250 ppmv at 6% O2 dry). This value was the contractual objective of the NO_x reduction retrofits described here.

2. DEVELOPMENT OF THE ADVANCED FW AF TECHNOLOGY

To enable the FW AF technology to fire fuels with lower ranges of volatile matter and produce lower levels of NO_x emissions, a comprehensive R&D program was undertaken in the late 1990s. The rest of this section summarizes the new components tested and the results of this program. Additional information with extensive references can be found elsewhere[12].

2.1. Test Coals

Table 2 compares the coals tested under the FW AF development program. The coal blend had equal parts of Somerset, Pennsylvania bituminous coal and the Kocher anthracite, which was also tested separately. Notice in particular the differences in volatile matter (VM) and hydrogen (H) among these test coals.

TABLE 2: FW AF Test Facility Coals Analysis (As Received Basis, ASTM Standards)

	Analysis, % by weight							HHV[c]	HGI[d]
Coals (ASTM Group)	**VM[a]**	Ash[a]	H_2O[a]	C[b]	**H[b]**	N[b]	S[b]	Btu/lb (kcal/kg)	
50%/50% Blend (~semi-anthracite)	**13.5**	11.	9.1	72.9	**2.9**	1.4	1.	13,550 (7,530)	68
Kocher, Pennsylvania (anthracite)	**6.9**	11.3	11.5	72.4	**2.1**	1.0	0.7	13,000 (7,220)	42
Carbonar, Spain (anthracite)	**5.**	19.5	7.6	68.5	**1.**	0.7	0.7	12,850 (7,140)	43

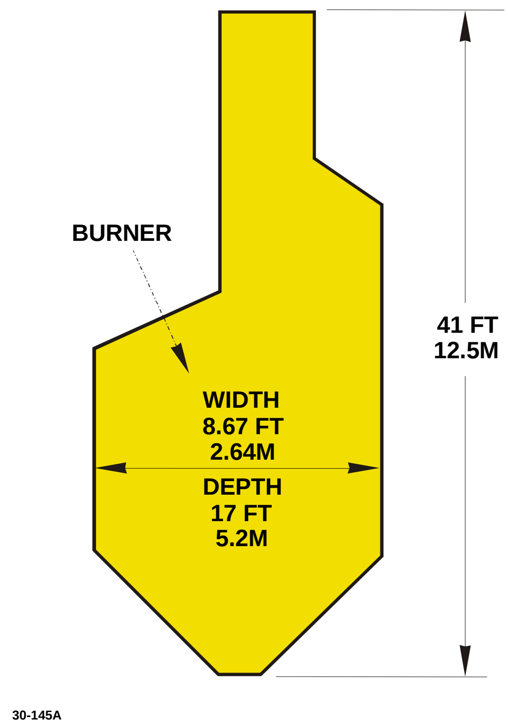
a) Proximate Analysis: Volatile Matter (VM) Ash and total moisture (H_2O)
b) Ultimate Analysis: elements as shown
c) Higher Heating Value
d) Hardgrove Grindability Index

Low volatile coals are better compared by the USA ASTM classification parameter of volatile matter (VM) on dry, mineral-matter-free basis, developed to deduct the non-burnable fraction of the volatile matter. Both ASTM groups to which the above coals belong are part of the Anthracite Coal Class.

From an ignition standpoint, a laboratory-determined ignition temperature, known as Reactivity Index (RI), is more important to the FW AF design than the VM content. This RI of low volatile fuels correlates better with coal hydrogen content than with VM[2].

2.2. Combustion Systems
The FW Combustion and Environmental Test Facility (CETF) located in Dansville, New York has one FW ball mill. The furnace was originally designed for arch firing. This water-cooled furnace side elevation and overall dimensions are given in Figure 3. Maximum furnace heat input is 75 MM BTU/h (22 MW_{th}).

FIGURE 3: FW AF Test Facility Furnace Sketch



For this investigation the CETF was reconfigured from horizontal firing to arch firing with one standard FW Double-cyclone Arch Burner and air supply system, same as shown in Figure 2.

Two subsequent modifications at the CETF known as “Fuel Preheat Nozzle” and “Vent-to-OFA” will be described next.

2.3. New components.
Figure 4 illustrates the modification of an existing FW AF burner nozzle design into a Fuel Preheat Nozzle. This FW-proprietary modification[13] involves shortening the fuel nozzle and substituting a hollow cylinder ("core") for the rod that supports the standard flow-straightening vanes. This modification allows for increased venting of cold primary air, while maintaining the velocity for proper penetration of the flame. This design also favors the mixing of the cooler coal with the surrounding hot arch ("tertiary") air before it reaches the furnace, because the remaining passage is narrower.

Besides enhancing ignition, the fuel preheat results in char formation (coking, or gasifying by pyrolysis) at higher temperatures that yield more volatiles (increased gasification efficiency). This is favorable to lower NO_x when there is air staging at the burner level, as in the classic FW AF technology.

FIGURE 4: Comparison of Classic and Fuel Preheat FW AF Burners

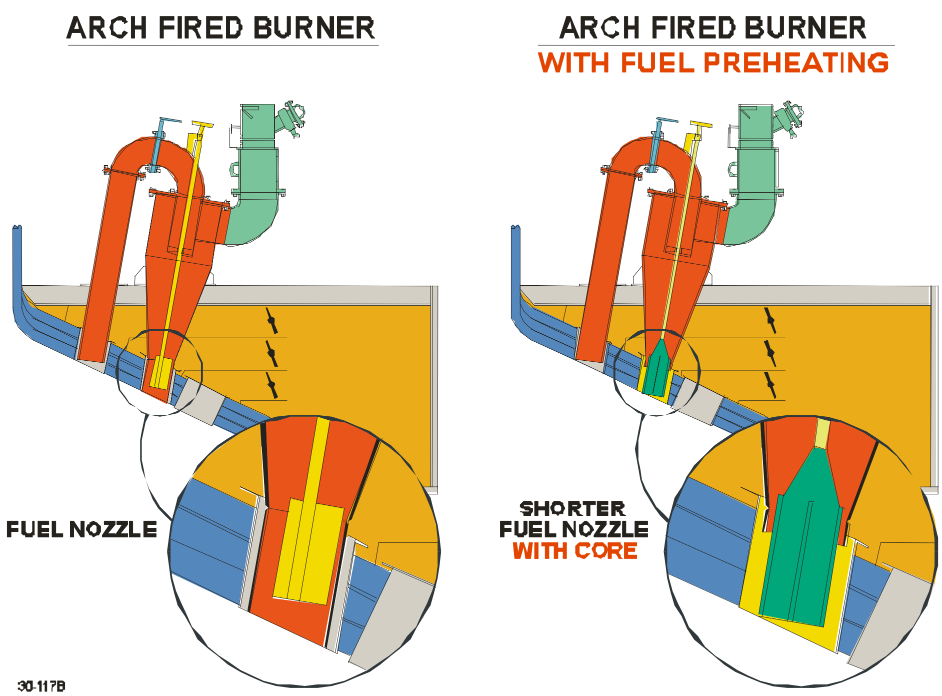
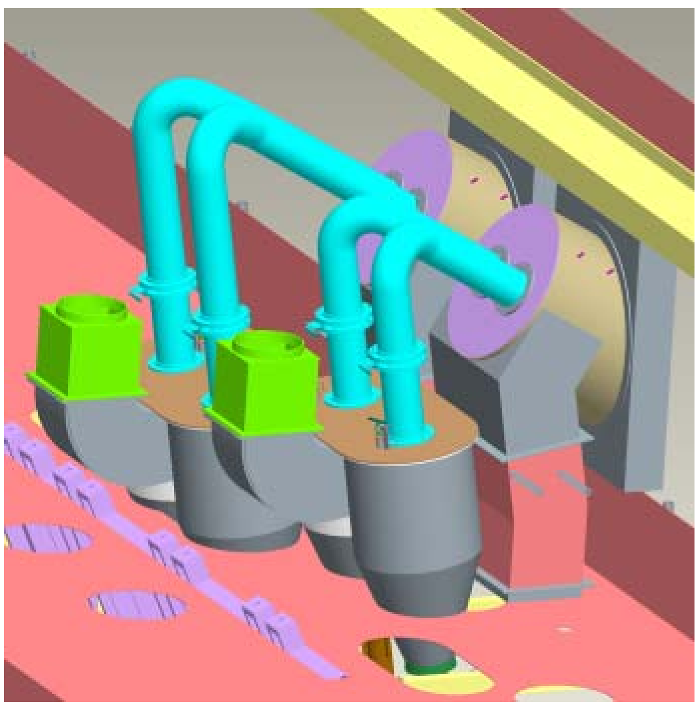


Figure 5 is a view of an additional air stage, discharging above the arch, consisting of one opening per burner with two concentric ports, called "peripheral" and "central". The latter integrates the FW proprietary Vent-to-OFA arrangement[14]. The coal/air conduits are not shown in the figure, for the sake of clarity.

Relative to the central port, the peripheral port is designed for low flow and high velocity, increased by swirling vanes, and is to be used preferentially at comparatively low OFA flows. Thus, within a broad range of OFA flows the OFA jet can achieve similar penetration in the furnace depth and can suction all of the up-flowing gases. The vent conveys most of the coal moisture and the finest and hence fast-burning fraction of the pulverized coal in a very lean phase, made even leaner by the central OFA. These OFA, moisture and finest coal mix with gases already depleted of oxygen by the burning in the lower furnace.

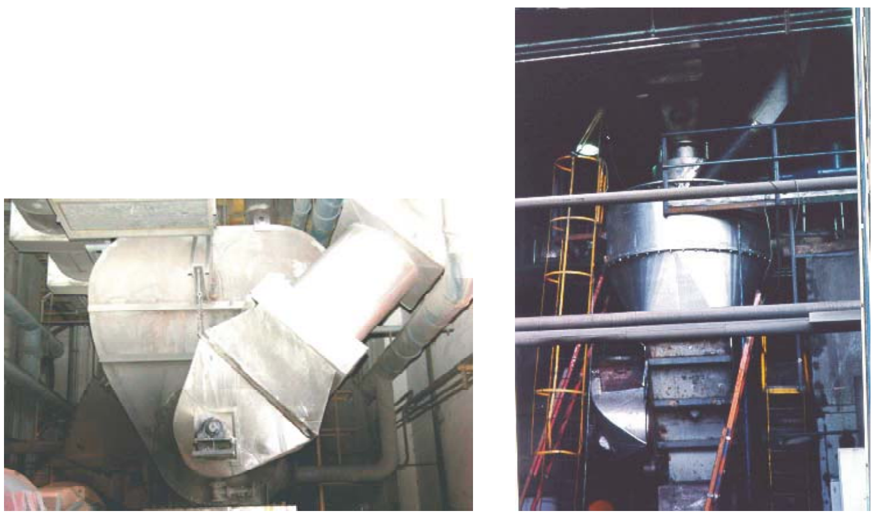
FIGURE 5: FW Double Cyclone Burners with Vent-to-OFA



Parallel development led to the static-adjustable "M Classifier" for ball mills, substituting for the original heart-shaped classifiers, first retrofitted to the six mills of the Compostilla, Spain 330 MW_e Unit 3.

Figure 6 shows the original classifier (left, looking towards one end of the mill) and this new M Classifier (right, mill end side view) as retrofitted within the space available underneath the raw coal feeders. Both new and original classifiers are an integral part of the mill end.[15].

FIGURE 6: Ball Mill Classifiers Photographs



Original Classifier | **New Classifier**

2.4. Tests Results Summary.

The standard nozzle modification into a Fuel Preheat Nozzle (Figure 4) allowed each of the coals listed in Table 1, including the 5% volatiles, 1% hydrogen Carbonar anthracite to be fired, without support fuel and at half load of the boiler, mill and burner. In fact, the temperature of the coal/air mixture entering the furnace could exceed 400°F (205°C) [12]. This is well within the range reached by indirect firing systems, which usually requires one extra bay in the plant and a multitude of additional equipment to operate and maintain. The conclusion is that the preheating accomplished by the Fuel Preheat Nozzle is equivalent to the preheating achieved by indirect firing, with significantly lower capital and O&M costs.

Each successive modification resulted in further reduction of NO_x at a given stoichiometry (air ratio) in the lower furnace. Figure 7 shows, for the coal blend, the relative NO_x as a function of unburned fuel. For a given NO_x, the corresponding unburned fuel was reduced by each modification. With the Fuel Preheat and Vent-to-OFA modifications, over 50% reduction of NO_x resulted in a less than doubling of the unburned fuel. Trends were similar with the other fuels, particularly for the right-hand curves that correspond to operation with OFA.

FIGURE 7: Relative NO_x vs. Unburned Fuel

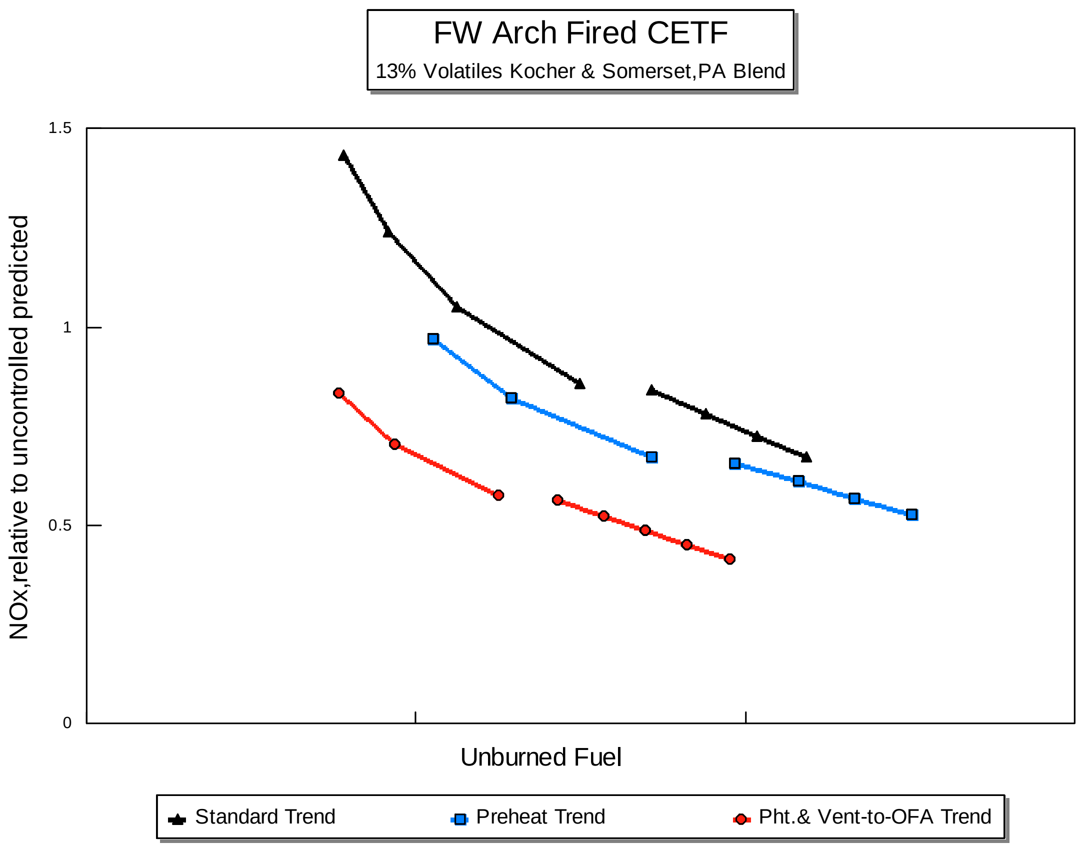
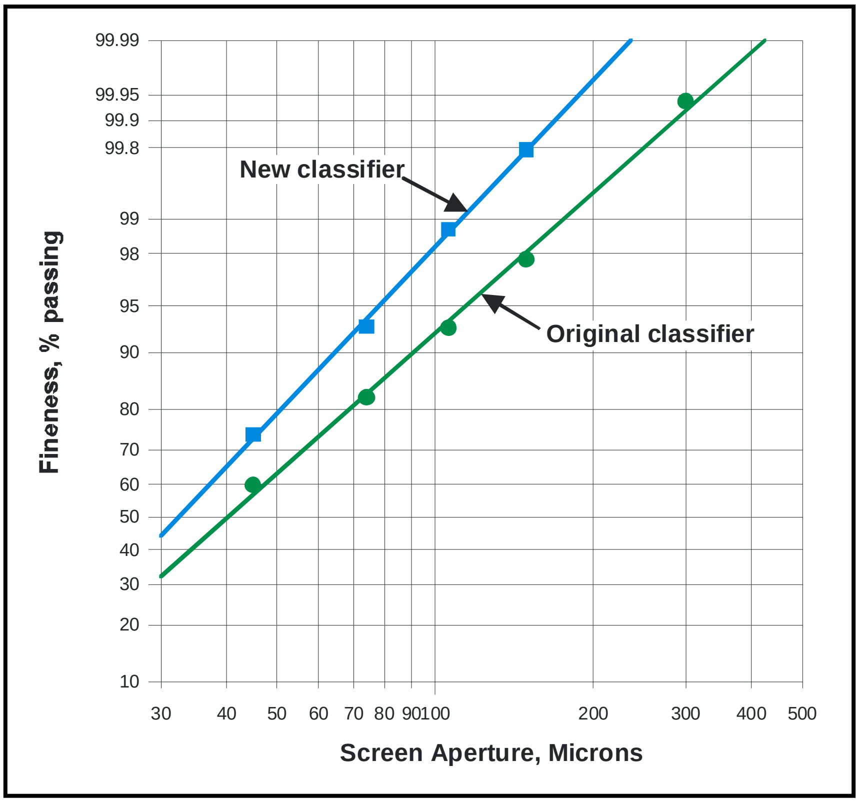


Figure 7 background tests were done at approximately constant coal fineness. It is foreseen that applying to the ball mill the new FW static-adjustable M Classifier, for these type of fuels more cost effective than rotating classifiers, will compensate for the unburned fuel loss increase caused by the NO_x reduction measures. This new classifier has decreased the unburned fuel loss by more than 50% in the FW AF 330 MW_e Compostilla, Spain Unit 3 mills retrofit[15].

Figure 8 shows, from mill tests with the same coal and mill load, actual size distributions of coal pulverized in a mill with the original classifiers and another with the new ones. Both mills were inspected during the weekend shutdown preceding the tests, and were found to be in a similar condition, particularly their grinding elements (drum liners and ball charge).

The mill product retained on 200 Mesh (74 microns) decreased from 18% to 7% (60% reduction) [15]. As illustrated elsewhere, the unburned fuel resulting from anthracite arch firing comes from pulverized coal particles with an initial size exceeding 74 microns[2]. However, in-furnace NO_x reduction results in even smaller size particles that are completely burned.

FIGURE 8: Fineness Improvement With New Classifier For The Same Coal and Mill Load



3. NARCEA, SPAIN PLANT 154 MW_e UNIT 2: BURNER RETROFIT TO LOWER THE RANGE OF FUEL VOLATILE MATTER[16]

The 2001 retrofit of the mechanically most novel and service-taxed new component, the Fuel Preheat Nozzle, to two Double-cyclone Burners of a central power station unit, was the concluding task of the Advanced FW AF technology R&D program.

3.1. Test Coals

Table 3 test coals analysis includes the 1% hydrogen Carbonar coal sampled at the AF CETF and sampled when testing at the Narcea 2 FW AF unit, as well the coal normally fired at that time by this power station.

TABLE 3: Narcea 2 Test Coals Analysis

CETF Carbonar and Narcea 2 2001 Test Coals Analysis (As Received Basis, ASTM Standards)

	Analysis, % by weight							HHV[c]	HGI[d]
Coals	**VM[a]**	Ash[a]	H_2O[a]	C[b]	**H[b]**	N[b]	S[b]	Btu/lb (kcal/kg)	
CETF Carbonar (anthracite)	**4.97**	19.54	7.62	68.49	**0.99**	0.67	0.68	12,851 (7,140)	43
Narcea 2 Carbonar (anthracite)	**5.71**	21.63	4.82	70.5	**1.05**	0.74	0.78	10,520 (5,840)	43
Narcea 2 Imported (semi-anthracite)	**8.56**	15.57	4.56	75.66	**2.59**	1.11	0.36	12,063 (6,700)	48

a) Proximate Analysis: Volatile Matter (VM) Ash and total moisture (H_2O)
b) Ultimate Analysis: elements as shown
c) Higher Heating Value
d) Hardgrove Grindability Index

Notice, in particular, the lower volatile matter (VM) and hydrogen (H) contents of the Carbonar coals as compared to the Imported coal, which also has somewhat higher grindability (HGI). The heating value (HV) of the Narcea Carbonar coal is markedly lower. Consequently, compared to the Narcea Carbonar coal the Narcea Imported coal should in principle be easier to ignite and lend itself to a finer grind, which favors faster and more complete burn-up.

3.2. Combustion System

The 154 MW_e Narcea Unit 2 has a furnace and combustion system similar to those shown in Figures 1 and 2, including four FW ball mills and sixteen FW Double-cyclone Arch Burners.

3.3. New Components

The owner allowed FW to design, supply and erect the Fuel Preheat modification of Narcea 2 burners No 9 (rear-left corner) and 11, both fed from the same end of mill 4. The other end of this mill feeds burners No. 13 and 15 in the rear arch, same as the modified burners. This modification took place during the Narcea 2 scheduled shutdown that started in May 2001. The previous Figure 4 depicts this Fuel Preheat burner modification.

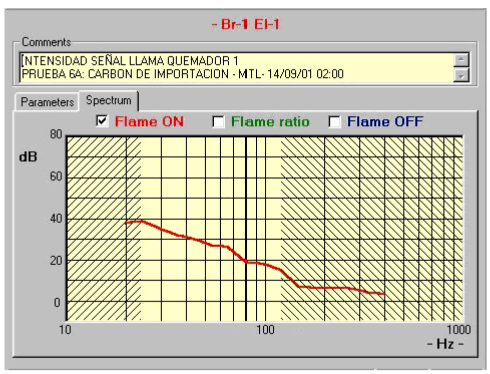
3.4. Test Results Summary

The most significant Narcea 2 modification test was run at low load, with the 1% hydrogen coal. This test duration was 6 ½ hours. The test goal of operating without oil support in the ½ arch with the modified burners was achieved. At ~ 4 ½ hours into the test the load of mill 4, the only one feeding this same-arch burners 9 (modified), 11 (modified), 13 and 15, was reduced to 60% of the mill load at MCR. The flame of modified coal burner 9 looked good, after mill load reduction, from both the observation door just above the furnace hopper knuckle and the observation door just below the arch.

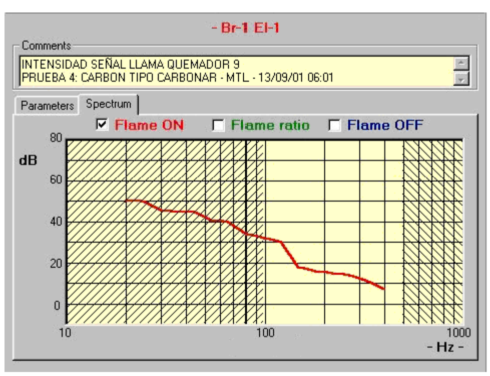
The flames were also evaluated quantitatively by analyzing the flame detector signal with the commercial flame scanning equipment of FW-subsidiary FI Controles, SA. The Flame Intensity (dB) vs. Frequency (Hz) characteristic was obtained by repeated filtering of the signal.

After mill load reduction during this test, the flame characteristic of the unsupported modified coal burner 9 was similar to that of coal burner 1, which was supported by its neighboring coal and oil burners. Figure 9 compares the characteristics of these two corner burners when their firing arrangement was identical to that of burner 9 during the previously discussed test, with neither support oil nor active burner next to it. Burner 1 case was also at 60% boiler load but firing the better, imported coal. In spite of the fuel and operating conditions being less favorable, the characteristic of modified burner 9 is clearly better (higher intensity at any frequency) than the one of the original burner.

FIGURE 9: Flame Characteristics Comparison: Original Burner with 2.6% Hydrogen Coal at Low Boiler Load and Modified Burner with 1% Hydrogen Coal, Low Boiler Load and Low Mill Load



Original Burner



Modified Burner

4. SUNBURY, USA PLANT 2 x 100 MW_e UNITS 1 & 2: NO_x REDUCTION SYSTEM RETROFIT

In response to a U.S. Environmental Protection Agency's Pennsylvania State Implementation Plan (EPA SIP) the contractual objective of the Sunbury, USA Units 1 and 2 retrofits in 2002 was to reduce the NO_x by more than 50% to 0.43 lb/10^6 BTU (~510 mg/Nm^3).

4.1. Test Coals

Table 4 shows analysis of the coals of the baseline testing and of the low NO_x testing coal that is also currently being burned at Sunbury 1 & 2.

TABLE 4: Sunbury 1 & 2 Coals Analysis (As Received Basis, ASTM Analysis)

	Analysis, % by weight							HHV^c	HGI^d
Coals	**VM^a**	Ash^a	H_2O^a	C^b	**H^b**	N^b	S^b	Btu/lb (kcal/kg)	
Baseline Tests Silt & Buck (semi-anthracite)	**7.58**	33	13.87	48.16	**1.26**	0.62	0.53	7,504 (4,170)	63
Low NO_x Tests Silt (anthracite)	**6.71**	31.71	15.67	48.27	**1.43**	0.63	0.53	7,598 (4,220)	71

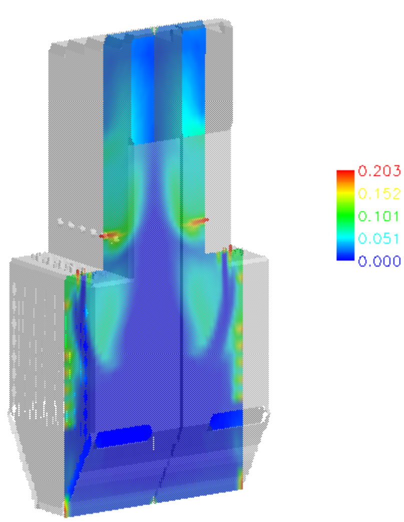
a) Proximate Analysis: Volatile Matter (VM) Ash and total moisture (H_2O)
b) Ultimate Analysis: elements as shown
c) Higher Heating Value
d) Hardgrove Grindability Index

Both coals are local and include low-quality anthracites, rejects from past coal cleaning operations.

4.2. Combustion System

The Sunbury units 1 and 2 each has two boilers. Each boiler has about 50 MW_e capacity, two FW ball mills and twelve burners. Figure 10 is a CFD model of the furnace of one of these boilers, showing the mole fraction of O_2 in a plane bisecting burners that predicted proper flame penetration. Notice the six clusters of nozzles on the arch in full view, each corresponding to one of the six burners on this arch. The furnace exit plane is seen at the top center, meaning that the arches of this furnace are located on the side walls instead of on the front and rear walls like in the current design (refer to Figure 1).

FIGURE 10: Sunbury 1 & 2 Furnace



4.3. New Components

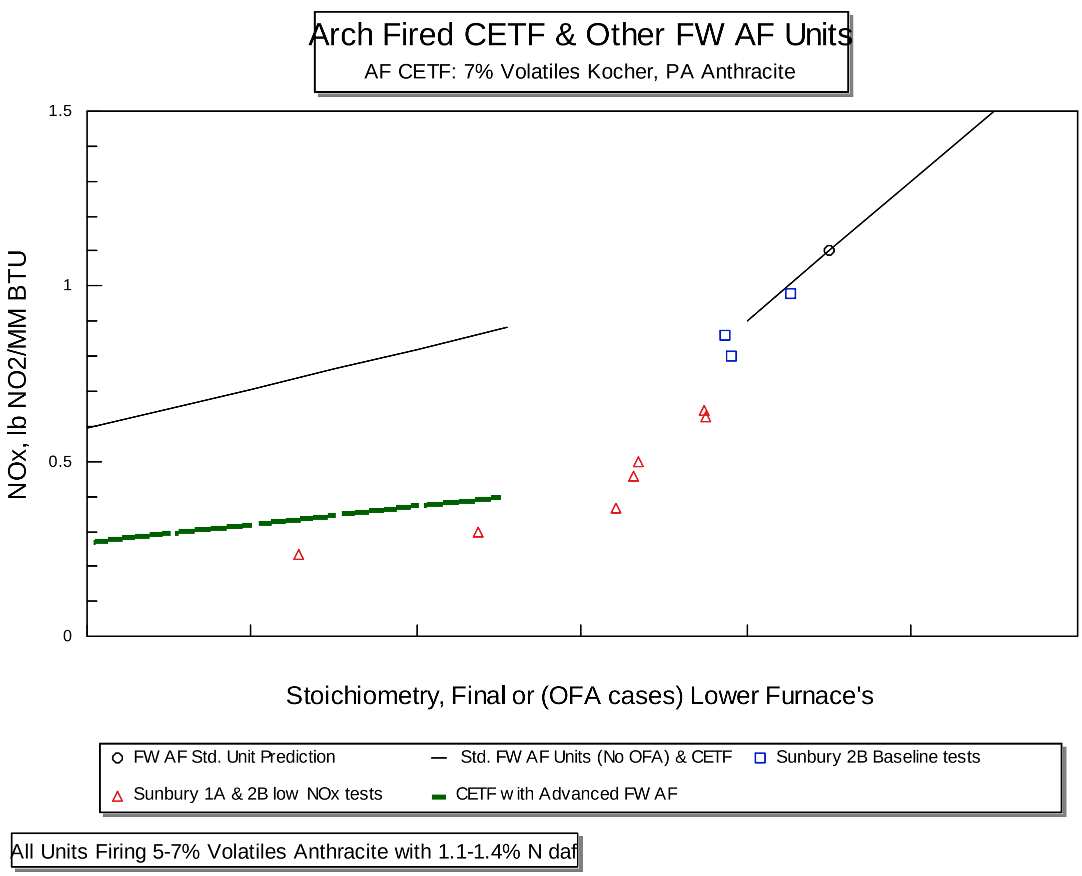
The four furnaces of the Sunbury Units 1 and 2 were modified by the addition of:

- A conventional boundary air system, to counteract potential slagging of the lower furnace even under the sub-stoichiometric conditions conducive to lower NO_x.
- The Fuel Preheat Nozzle modification to FW Double-cyclone Arch Burners, as per Figure 4.
- An additional air stage, discharging above the arch consisting of one opening per burner, as seen in Figure 10, with two concentric ports integrating the Vent-to-OFA in an arrangement functionally equivalent to that shown in Figure 5.

4.4. Results Summary

Figure 11is a plot of NO_x at the AF CETF and from Sunbury 1 & 2 tests, versus lower furnace stoichiometry (air ratio). This is explained next. “Screening” tests at the AF CETF were in accordance with the design-of-experiments (DOE) method. A practical application of the DOE method[17] was used to analyze “effects (of air damper settings) and interactions” on the results, except for appying sets theory (Boolean algebra) so that two factors that are “negative” from the NO_x reduction standpoint cannot become “positive” when jointly applied. The conclusion was that, except for settings conducive to unacceptable unburned or conversely to very high NO_x, the key parameter for the FW AF designs is the stoichiometry (air ratio) in the lower furnace. This stoichiometry coincides with the final or furnace exit stoichiometry in cases without OFA (right hand side straight line in Figure 10, also valid for all units of classic FW AF design and operation). As seen here, Sunbury 1 & 2 NO_x reduction improved relative to the AF CETF[16].

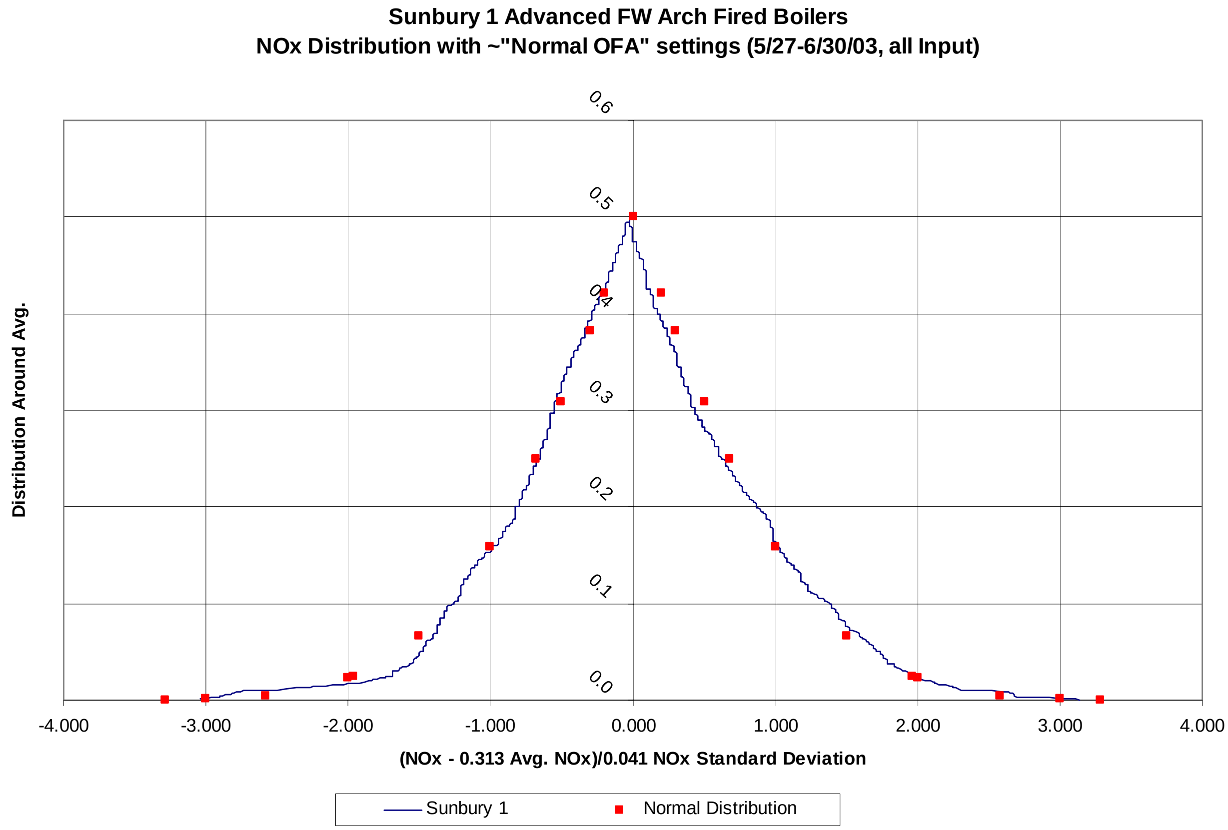
FIGURE 11: NO_x vs. Lower Furnace Stoichiometry (Air Ratio)



Typical long-term hourly NO_x data, available through the USA EPA and corresponding to Sunbury's typical low-quality 7% volatiles anthracite-fired with fixed air damper settings, follow a statistical distribution nearing the Normal (Gaussian) Curve, as seen in Figure 12. At this low level of NO_x its emission is not much dependent on boiler load hence to fuel input.

The average of ~0.31 lb/MM BTU (~340 mg/Nm3) was chosen for that May 1 to September 30 Ozone Season to generate NO_x credits while keeping the unburned low enough to sell the ash, without resorting to mill modification. The ~0.13 ratio of standard deviation to average NO_x seems fairly typical, regardless of NO_x level, as evidenced by analysis of similarly chosen off-season, higher NO_x data. Therefore, this ratio can be used to choose the NO_x setting resulting in compliance when no automated control is available.

FIGURE 12: Long-term Hourly NO_x Statistical Distribution and Gaussian Curve Dots



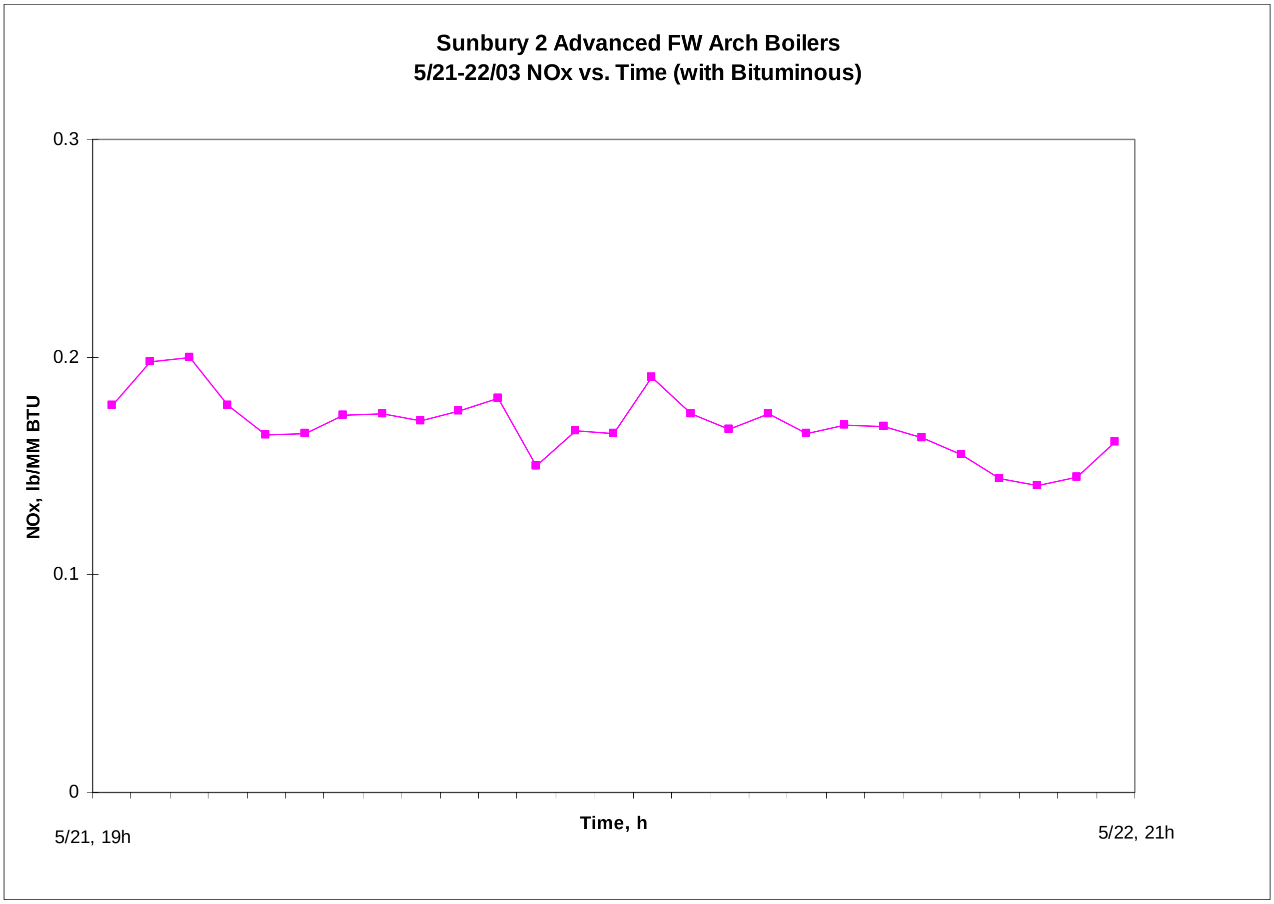
Incidentally, the corresponding long-term periodic data on unburned in flyash also followed a statistical distribution approaching the Normal (Gaussian) Curve and having ~0.25 ratio of standard deviation to average, regardless of unburned level.

Consistent operation with Sunbury's typical low-quality 7% volatiles anthracite has been on occasions at 0.2 lb/10^6 BTU (~250 mg/Nm^3).

The CO emission guarantee of 100 ppmv was amply met, helped by improved air and gas mixing as indicated by the more even O_2 readings when OFA is in service[16]. Final steam de-superheating, before and after the retrofit of the Advanced FW AF, are similar.

As an illustration of the fuel flexibility of the Advanced FW AF technology, Figure 13 shows consecutive hourly NO_x data from Sunbury 2 while firing a low-volatile (18% VM) bituminous coal. Although no attempt was made to minimize NO_x, the average of this period was 0.17 lb/10^6 BTU (~200 mg/Nm^3). The unburned fuel in the flyash was markedly lower than with anthracite.

FIGURE 13: Hourly NO_x with 18% Volatiles Coal



5. SEOCHEON, KOREA PLANT 2 x 200 MW_e UNITS 1 & 2: NO_x REDUCTION SYSTEM RETROFIT

Answering to regulations by the Republic of Korea[10], the contractual objective of the Seocheon, Korea Units 1 and 2 retrofits, in 2005 and 2004 respectively, was to reduce the NO_x by some 50% to 250 ppmv at 6% O2 dry, equivalent to ~0.43 lb/10^6 BTU (~510 mg/Nm^3).

5.1. Coal

Table 5's analysis of the contractual coal for the retrofit proved representative of the coal available during retrofit commissioning and testing.

TABLE 5: Seocheon Retrofit Contractual Coal Analysis (As Received Basis)

	Analysis, % by weight							HHV[c]	HGI[d]
Coals	**VM[a]**	Ash[a]	H_2O[a]	C[b]	**H[b]**	N[b]	S[b]	Btu/lb (kcal/kg)	
Korean Anthracite	**4.42**	30.35	9.14	57.47	**1.02**	0.35	0.38	8,670 (4,817)	70

a) Proximate Analysis: Volatile Matter (VM) Ash and total moisture (H_2O)
b) Ultimate Analysis: elements as shown
c) Higher Heating Value
d) Hardgrove Grindability Index

5.2. Combustion System

The 2 x 200 MW_e Seocheon, Korea Units 1 and 2 were designed by "Company A" of Table 1, therefore:

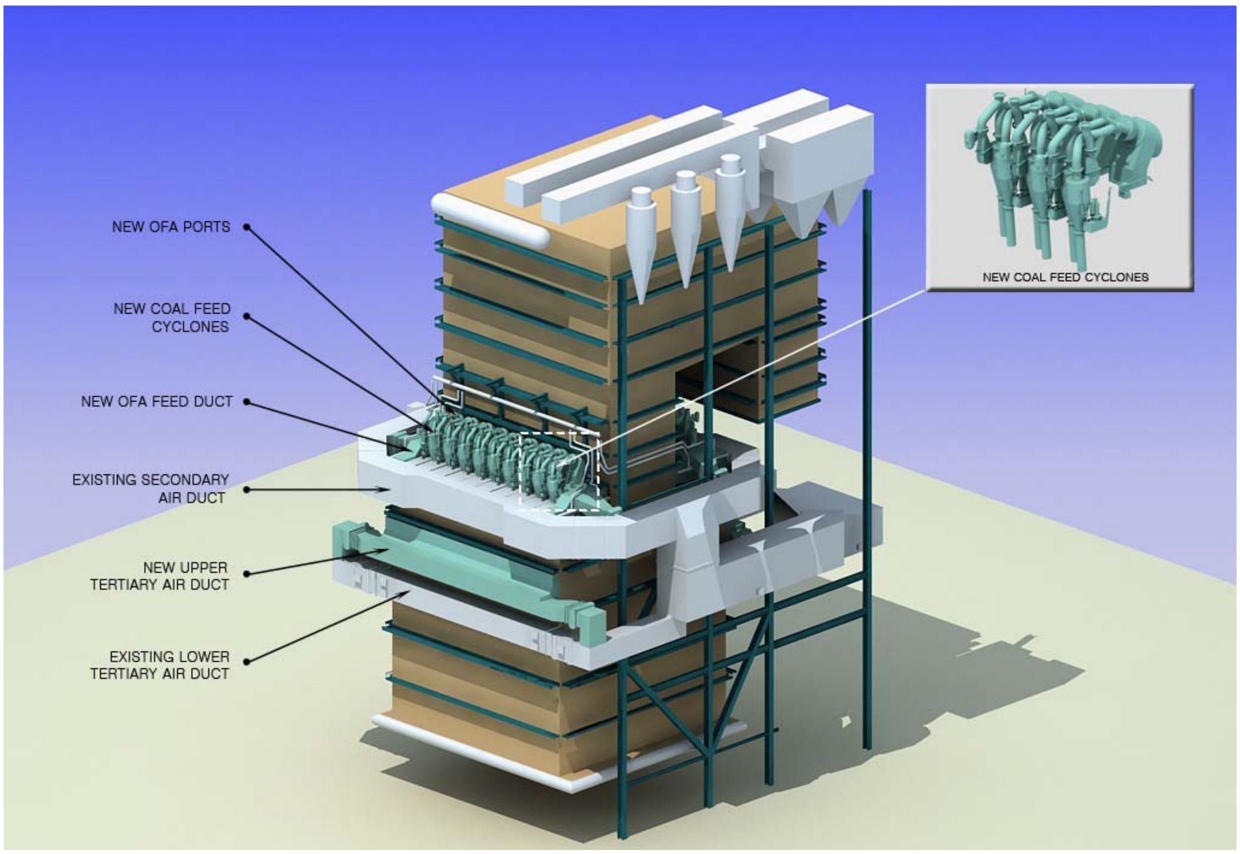
- It has an indirect firing system, which includes PC cyclones and PC bag filter collectors as can be seen in grey color on the top of Figure 14, next page. PC bins and PC feeders, not shown in the figure, are just underneath the PC cyclones.
- It provided only ~10% of the combustion air through the vertical walls. The front vertical wall supply ducts and plenum are also shown in gray color about 1/3[rd] of the way up on the boiler in Figure 12.
- The boiler (water-steam) system, including the furnace walls that were to be modified with OFA openings, has pump-assisted circulation.
- It had no PC separating capability upstream of the 2 x 20 burner nozzles, which each discharged through a slot.

5.3. New Components

As shown by Figure 14 in light-green color, from top to bottom these were the main additions or modifications supplied and/or designed by FW:

- 18 OFA ports were placed above the arch.
- 2 x 18 FW cyclones were added above the arches and each with the round-discharge Fuel Preheat Nozzle fitting in the pre-existing slot. Each coal discharge slot originally next to a corner was blocked, to respect the standard FW burner-to-side wall clearance.
- OFA supply ducts and a plenum were located on each arch next to the upper front or rear wall.
- New air wall ("tertiary" as per OEM) air supply ducts and plenum were provided for each arch in-between the pre-existing arch air and air wall plenums.
- New air wall openings (not seen in the figure) were made, below each arch and spanning the height of the corresponding new "tertiary" plenum shown in the figure.

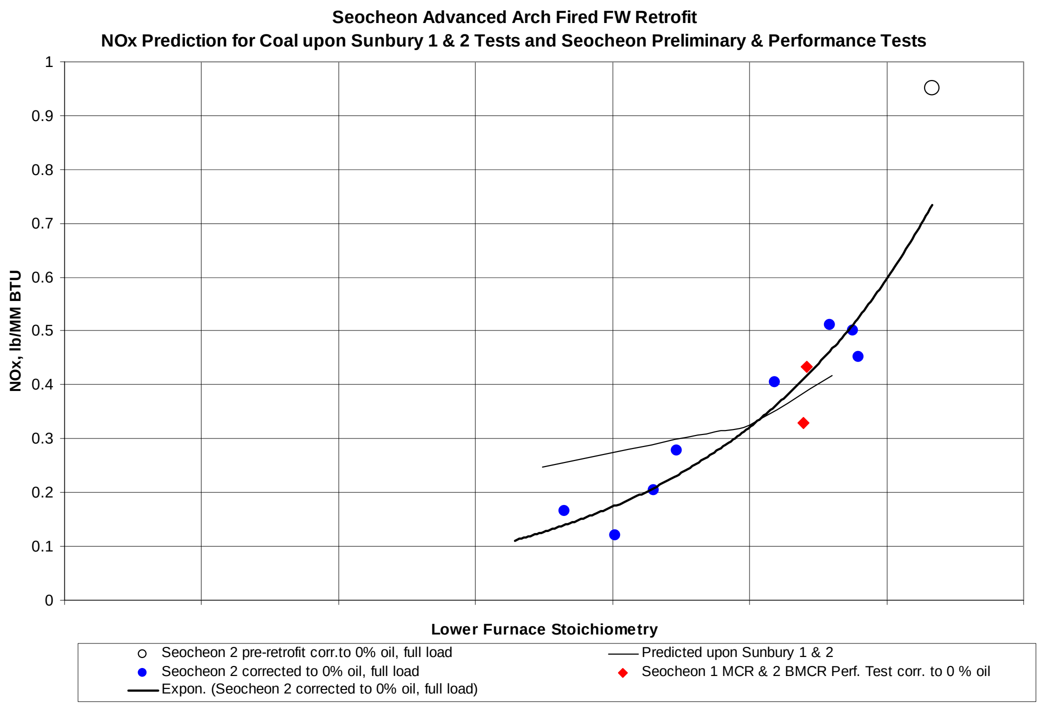
FIGURE 14: Seocheon Boiler Perspective View



5.4. Test Results Summary

Figure 15 is a plot of coal-generated NO_x versus lower furnace stoichiometry (air ratio) including the prediction for Seocheon based on Sunbury 1 & 2, the baseline test and the post-retrofit tests results. The guaranteed NO_x of 0.43 lb/10^6 BTU (~510 mg/Nm^3) was met.

FIGURE 15: NO_x vs. Lower Furnace Stoichiometry (Air Ratio)



For commercial reasons, the customer operates at MCR with 20% heat input from fuel oil. According to USA EPA data from the then fuel oil-fired Delaware City Refinery Unit 4, a FW AF boiler previously firing petcoke and nowadays clean gas as per local environmental requirements, the average NO_x was 0.2 lb/MM BTU. Seocheon oil guns discharge in parallel with the adjacent coal nozzles, currently exhibiting very narrow and long flames, the same as the coal flames, which results in limited mixing. During these tests, few oil guns were in service. Furthermore, in Seocheon the supply of air to the air walls was and remains common for all the burners of an arch. Therefore, since oil burns far faster than coal, the oil combustion was generally complete in the lower furnace, as in mentioned Delaware City boiler, which has no OFA. Consequently, one may expect at Seocheon the NO_x from oil to have been ~0.2 lb/MM BTU, hence the ~20% oil input to have contributed ~0.2 x 0.2 = 0.04 lb/MM BTU. In Figure 15 any actual test NO_x that exceeded 0.2 lb/MM BTU has been corrected slightly upwards to "coal-generated NO_x" as follows:

Coal-generated NO_x = (Actual NO_x – 0.04) / 0.8

Other guarantees met covered the unburned fuel loss as well as CO and de-superheating spray flows, which were similar to the respective pre-retrofit values.

6. COMPOSTILLA, SPAIN PLANT 350 MW_e UNIT 4: NO_x REDUCTION SYSTEM PARTIAL BOILER RETROFIT

The contractual objective of NO_x reduction retrofits in Spain is to meet the requirements of the 2001 European Union's Large Combustion Plants Directive[11] (EU LCPD) that imposed new limits to existing units, effective January 2008. These included 500 mg/Nm^3 (~0.42 lb/10^6 BTU) NO_x limit for solid fuels exceeding 10% volatiles. The choice of Spain to comply as a nation-wide "bubble" by its National Emissions Plan means that a unit to which the Directive allowed higher emissions, like the 1200 mg/Nm^3 (~1 lb/10^6 BTU) NO_x for solid fuels with less than 10% volatiles, generates credits when emissions are lower than this limit.

Previous parametric testing at the Compostilla, Spain Central Power Station 350 MW_e Units 4 and 5, of classic FW AF design, had shown that their most practical operation with the 7% volatiles coal was at some 1300 mg/Nm^3 (~1.1 lb/10^6 BTU) NO_x[18]. The owner decided to proceed, during scheduled outages, with retrofitting six burners of Unit 4 for NO_x reduction demonstration with the Advanced FW AF technology[19]. Normally a maximum 20 of 24 burners (5 of 6 mills) are sufficient at MCR with the large boilers of this plant when firing the same Bierzo region's coal[15]. After the partial retrofit completion, in 2005 the Compostilla Customer declared[19] that this initial trial was deemed applicable to the other [large] units of the power station and that there is the intent to proceed shortly with Units 5 and 3, the last a 330 MW_e FW AF boiler.

7. CONCLUSIONS

The status of the application to central power stations of the Advanced FW Arch Firing is summarized in Table 6.

TABLE 6: Advanced FW Arch Firing Central Stations Applications

Job	OEM	MW_e per boiler	Burners each unit	Year completed
Narcea 2, Spain (Partial, Preheat Nozzle only)	FW	154	2 of 16	2001
Sunbury 1 & 2, USA	FW	4 x 50	12	2002
Seocheon 1 & 2, Korea	"A"	2 x 200	20	2004 and 2005
Compostilla 4, Spain	FW	350	6 of 20 in service	2005

In view of the foregoing, Table 1 is revised into Table 7.

TABLE 7: Comparison of AF Designs with NO_x Reduction

Company	**FW (Advanced AF)**	**A + OFA**	**B + OFA**
Burner Type Burner Discharge	Separating Round	Slot	Slot
Firing Type	Indirect-equivalent (Was Direct)	Indirect	Direct
Minimum* Volatiles, %	4	9.3	11
Minimum* Hydrogen, %	1 (Was 1.8)	2.2	2.8
Reported NO_x, mg/Nm3 (< / > 10% Volatiles)	<250/ <200 (Was <1300 / <650)	1320 (was 1650) Predicted by FW	1190 (was 1490) Predicted by FW
~Vertical wall air, %	70-OFA	10	0

* NOTE: content required for 40-50% boiler load operation without support fuel.

To bring into perspective the NO_x level attainable by the Advanced FW AF design, let us mention that it is included as an example of Best Available Techniques (BAT) in the European Union (EU) "Integrated Pollution Prevention and Control Reference Document on Best Available Techniques for Large Combustion Plants"[20] [LCP BREF] of May 2005.

In this EU LCP BREF, the executive summary tabulates for PC firing a "NO_x emission level associated with BAT" range of 90 – 200 mg/Nm^3 attainable by "Combination of Pm [primary measures ~ in-furnace reduction] in combination with SCR or combined techniques". A footnote in the same Table 7 reads "The use of anthracite hard coal may lead to higher emission levels of NO_x because of the high combustion temperatures". Nevertheless, from the above reported results it follows that, even prior to optimization of its operation, the Advanced FW AF technology on its own approaches the EU's BAT-related NO_x levels for PC firing. The current EU NO_x limit for new pulverized fuel fired boilers is 200 mg/Nm^3, regardless of fuel volatile content[11].

Returning to the above-mentioned EU LCP BREF Table 7 footnote, in the applications of the Advanced FW AF to date it may seem contradictory that the NO_x lower level has decreased as boiler size increased (see Figures 11 and 15). This is in spite of increasing temperatures in the lower furnace (volume below the arches) with boiler size because of the corresponding normal decrease in the lower furnace's ratio of surface to volume. However, when decreasing with OFA the NO_x from low-volatiles fuels the controlling reaction has to be the reduction of the NO by the coal char. Although a higher temperature in the furnace increases the generation of thermal NO_x, in the Advanced FW AF technology applications up until now such an increase has been surpassed by the higher NO-char reaction rate at higher temperatures[21]. As to other effects, specifically those on the Advanced FW AF technology proprietary features, of a higher temperature in the lower furnace:

- It enhances the gasification by pyrolysis accomplished by the Fuel Preheat Nozzle[13] that, in combination with the air staging usual to the FW AF Burner, inhibits NO formation from fuel Nitrogen in the increased volatiles via mechanisms common to all low NO_x burners[22].
- It does not affect the production of NO by the fast-burning coal fines because, thanks to the cyclone burner Vent-to-OFA[14], they can be discharged above the arches where they mix with gases already depleted of oxygen by the burning of coal in the lower furnace instead of going into the very high O_2 region just below arches, same as in the classic FW AF.

As a result of a substantial NO_x reduction, the Advanced FW AF technology design may double the unburned fuel loss in efficiency. However, it is approximately the same in proportion as the increase resulting from low-NO_x horizontally fired burner retrofits. This efficiency loss increase can be counteracted by retrofitting more efficient classifiers to the mills, like the new adjustable-static M Classifier for ball mills. The M Classifier first full retrofit, in the 330 MW_e Compostilla, Spain Unit 3, has reduced the unburned fuel loss to less than half the original unburned fuel loss[15].

Except for Compostilla, no wall blowers are available in the lower furnace of any retrofitted unit. Nevertheless, subsequent operation of these retrofit units has not resulted in decreased unit availability because of slag buildup. The carbon monoxide emissions and the overall furnace thermal performance, before and after the retrofit of the Advanced FW AF technology, are similar.

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