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Multi-Pollutant Measures Database

Final Interim Report: Meeting the NOx National Emission Ceiling for 2010

June 2008

Entec UK Limited

Report for

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1. Introduction

1.1 Purpose of this Report

The purpose of this interim report is to consider how the UK could achieve compliance with the NOx National Emission Ceiling (NEC) for 2010 in a cost-effective manner. This report provides a summary of projected emissions for the UK for 2010, potential beyond business as usual (BAU) measures and associated costs and potential emission reductions, based on best available information within the timescales of the report. A range of compliance scenarios have been developed with different combinations of measures that could be applied to seek to meet the 2010 NOx NEC target. This interim report has not considered the multi-pollutant approach as it has only focused on NOx.

It is important to note that this report is a high level review (undertaken in a short time period) of the most effective measures (in terms of emission reductions) for the highest emitting sectors. It forms the basis for consideration of compliance solutions for the 2010 NOx NEC target but is not a comprehensive review of all possible measures or sectors.

The purpose of the overall study is to develop a multi-pollutant measures database, and the second stage of this study will focus on the development of beyond BAU measures for 2015 and 2020.

The majority of the work to develop a multi-pollutant measures database is undertaken under the *"Scientific support for national and international policy"* contract (SSNIP). The work carried out for the interim report, with regards to how the UK can achieve compliance with the NOx NEC for 2010, is mostly undertaken under the "*The Preparation of Regulatory Environmental Impact Assessments in Relation to Proposals for Air Quality Legislation"* contract (RIA).

1.2 Background

1.2.1 The National Emission Ceilings Directive

The National Emission Ceilings Directive (NECD, 2001/81/EC)[1] sets National Emission Ceilings (NECs) for four pollutants causing acidification and eutrophication and ground-level ozone pollution. A key requirement of the Directive, as stated in Article 4, is that by 2010 and thereafter Member States must limit national annual emissions of sulphur dioxide (SO2), nitrogen oxides (NOx), volatile organic compounds (VOCs) and ammonia (NH_3) to the ceilings specified for each Member State, presented in Annex I of the directive.

Implementation of the NECD requires Member States to develop national programmes for the progressive reduction of the relevant pollutants, in addition to the provision of information on

[1] OJ L 309, 27.11.2001, p.22 - 30

the likely impact of policy measures on emissions in 2010. EU15 Member States were obliged to develop and submit the first national programmes in 2002, and, where necessary, revise these in 2006 according to Article 8. The new Member States were required to submit national programmes for the first time in 2006. The NECD further requires Member States to provide annually updated emission inventories and emissions projections for 2010, which will subsequently be made available to all other Member States.

Articles 9, 10 and 12 of the NECD set out the requirements for a review of the national emissions ceilings, incorporating further investigation of costs and benefits of achieving the ceilings. The Commission must report in 2004, 2008 and 2012 to the European Parliament and the Council on progress on the implementation of the ceilings and towards attaining the interim environmental objectives and the long-term objectives set by the Directive for 2020. The first progress report for 2004 has already been prepared by the Commission based on a draft prepared by Entec[2] as part of the Review of the NECD study undertaken in 2004-05.

A number of Member States are currently projected to exceed their NEC for NOx in 2010 and will need to implement additional measures in order to comply.

1.2.2 Revision of the NECD

The Commission has started the preparatory work for a legislative proposal to revise the NECD. The new proposal will set emission ceilings to be met by 2020 for the four pollutants already covered by the NECD and for primary emissions of $PM_{2.5}$. The Commission is focusing on three elements of the proposal; the objectives, baseline scenario(s) and sensitivity runs.

The objectives of the revised NECD will be similar to the objectives of the Clean Air For Europe (CAFE) Thematic Strategy on air pollution, which is required under the Sixth Environmental Action Programme[3]. The development of a baseline scenario(s) towards 2020 was undertaken by the International Institute of Applied Systems Analysis (IIASA) and was finalised in September 2006. Initial baselines were presented and compared at the 'Conference on Air Pollutant and Greenhouse Gas Emission Projections for 2020'.

The Commission has indicated that the revised NECD will include absolute emission ceilings for SO_2, NO_x, VOC and NH_3 as well as a relative ceiling (i.e. % reduction) for $PM_{2.5}$ that may be converted to an absolute ceiling in the future as emission inventories improve.

The National Emission Ceilings – Policy Instruments (NEC-PI) working group is assisting the Commission with preparatory work associated with the revision of the NECD by providing technical and expert advice regarding the modelling work currently undertaken and other aspects of possible revisions to the directive.

The NECD proposal was originally planned for adoption by the Commission in July 2007, although the Commission is now unlikely to propose a revised Directive including emission ceilings until summer 2008.

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[2] Available at http://ec.europa.eu/environment/air/pdf/nec_rev/final_report.pdf

[3] Available at http://ec.europa.eu/environment/air/cafe/index.htm

1.3 Structure of this Report

This report is structured around three main sections:

- Section 2 provides a short description of the methodology employed to undertake this work, including the selection of sectors and the standardisation of cost estimates;
- Section 3 presents the compliance scenarios developed to meet the 2010 NOx NEC target;
- Section 4 presents the conclusions.

More information on the underlying assumptions used to develop measures is provided in Appendix A on a sector-by-sector basis.

2. Methodology

2.1 Introduction

This section summarises the methodology used to prioritise sectors, assess the applicability of measures to reduce NOx emissions for 2010 and determine their possible uptake, costs and abatement efficiencies.

2.2 Emission projections

The 2005 UK National Atmospheric Emissions Inventory (NAEI) provides estimates of atmospheric releases of NOx and a wide range of other pollutants, as summarised in Table 2.1.

Table 2.1 UK BAU NOx emission projections (kt) for 2010 for NECD sectors only (using SNAP sector categories) (based on 2005 NAEI & UEP30)[1]

SNAP	Sector	NOx emissions
1	Combustion in energy and transformation industries	376
2	Non-industrial combustion plants	111
3	Combustion in manufacturing industry	168
4	Production processes	3
5	Extraction and Distribution of fossil fuels and geothermal energy	0
6	Solvent and other product use	0
7	Road transport	393
8	Other mobile sources and machinery[2]	240
9	Waste treatment and disposal	4
10	Agriculture	0
11	Other sources and sinks	1
	Total	**1,296**

[1] Projections for 2010 have recently been updated so that 2010 NOx emissions from petroleum refineries are now estimated to be 2kt less than what is presented in this study. Personal Communication with AEA Energy & Environment, 15th May 2008

[2] This sector includes sources such as railways, shipping (naval and coastal), aircrafts (military, domestic and international take off and landing, support vehicles), agriculture - mobile machinery, industrial off-road mobile machinery, house and garden machinery

The UK emission projections are based on the 2005 NAEI and the 'UEP30' energy baseline and have been developed using a series of assumptions for each sector[4]. The projections have been updated to take into account the Euro 5 and 6 vehicle emission standards recently agreed for LDVs[5].

It is important to note that it was not within the scope of this study to critique the emission projections. Therefore, for the purposes of this study, emission reductions and costs associated with specific measures have been estimated based on the emission projections above without change.

2.3 Selection of emission sources

The emission sources selected for inclusion in the main investigations on how the UK can achieve compliance with the NOx NEC for 2010 were determined based on their contribution to the total projected UK NO_x emissions in 2010 (those over 1% were considered to be a priority). Table 2.2 summarises the NOx emission projections in 2010[5] and the relative contribution of the sources considered in this report.

Table 2.2 NOx emission projections in 2010 and the relative contribution of the sources considered

SNAP code	Source	2010 NOx emissions (kt)	% to total 2010 NOx emissions
01	Offshore oil and gas - own gas combustion	54	4%
01	Power stations	281	22%
01	Refineries - combustion	31	2%
02	Domestic combustion	93	7%
03	Autogenerators	23	2%
03	Cement - non-decarbonising	23	2%
03	Iron and steel - combustion plant	14	1%
03	Other industrial combustion	90	7%
07	Road transport (all)	393	30%
08	Agriculture - mobile machinery	27	2%
08	Industrial off-road mobile machinery	70	5%
	Total of sources considered in this report	1,100	86%

[4] Key assumptions presented in AEA Energy & Environment (2007): Projected Emission Projections - The results and assumptions of the 2005 air quality pollutant emission projections. A report of the National Atmospheric Emissions Inventory, December 2007.

[5] Personal Communication with AEA Energy & Environment, 6th July 2007

SNAP code	Source	2010 NOx emissions (kt)	% to total 2010 NOx emissions
	TOTAL of all UK sources within scope of NECD	1,296	100%

The remaining sources contribute approximately 14% to total NOx emissions in 2010, with shipping being the highest contributor (7%) and other mobile sources and machinery the second highest (3%).

Shipping is not within the scope of this study. Once the measures database has been finalised then a separate workplan will be developed under the SSNIP contract to undertake a literature review of ship emissions abatement technology and to develop and integrate specific shipping measures into the database. This is likely to be an important area of work for feeding into the strategy for compliance with the 2010 NOx emission ceilings given that NOx abatement of ship emissions is expected to be particularly cost effective[6]. Other mobile sources and machinery (such as aircraft and railways) were not included as no measures were considered applicable for this sector for 2010.

2.4 Development of abatement measures

Abatement measures have been selected from the existing cost curve data for NOx developed by Entec under the Defra contract "Cost Curves for Air Pollutants" (April 2002 to March 2005) and have been transferred into a database of 'beyond BAU' measures'. Parameters within the database include;

- The measure and the sector
- Uptake by the sector (under BAU policies and potential scope for additional 'beyond BAU' uptake for 2010);
- NOx emission reduction efficiency;
- Operating life of measure within sector;
- Capital and operating costs;
- Total annualised cost.

In addition, further beyond BAU measures for NOx for 2010 have been included, taking into consideration measures developed under the AQSR, those proposed by other Member States and additional measures developed under other studies. Table 2.3 lists the measures that have been considered; these are described in more detail in Appendix A.

[6] It is important to note that only naval and coastal shipping emissions are included under the NECD.

Table 2.3 Measures considered for reducing emissions of NOx in 2010

Sector	Measures
Power Stations	Selective Catalytic Reduction (SCR)
Petroleum refineries – combustion	SCR
Offshore oil and gas - own gas combustion	Dry Low NOx emission technology
Domestic households	Gas fired appliances with tighter NOx emission standards
Cement Sector	Selective Non-Catalytic Reduction (SNCR)
Cement Sector	SCR
Iron and Steel works	SCR
Autogenerators & Other industrial combustion	Combustion Modification
Autogenerators & Other industrial combustion	SCR
Agriculture & Industrial off-road mobile machinery)	Further uptake of Stage II controls
Agriculture & Industrial off-road mobile machinery)	Early uptake of Stage IIIA controls
Road Transport	Speed limit enforcement
Road Transport	Transfer of freight from road to rail
Road Transport	Retrofitting SCR to HDVs
Road Transport	Retro-converting HDVs to use Compressed Natural Gas
Road Transport	Replacement of existing vehicles with hybrids
Road Transport	Euro VI standard for HDVs (including early uptake)
Road Transport	Low emission vehicles (LEVs)

It was not within the scope of this study to assess the economic impacts of the measures considered including impacts on competition and competitiveness. Sectors for which competitiveness impacts could potentially constitute a significant issue include those exposed to international competition. These include, but are not limited to, cement, petroleum refineries, iron and steel, the glass industry and the chemicals industry.

2.5 Costing

The methodology for the standardisation of the cost estimates is shown in Table 2.4 below[7].

[7] Agreed with Defra economists, 27-28th Nov 2007.

Table 2.4 Rules for the standardisation of cost estimates

Category	Standardised approach
Prices and inflation	Price estimates have been presented in 2007 Q4 prices (i.e. Nov 2007). The monthly retail price index (RPI) has been used to update cost valuations to more accurately account for inflation in the UK. The monthly RPI used can be found at: http://www.statistics.gov.uk/StatBase/tsdataset.asp?vlnk=229 This is slightly different to the approach used in the AQSR where prices were adjusted for inflation, assuming a rate of 2.5% p.a.
Exchange rates	The ECB Statistical data warehouse containing historical exchange rates has been used to convert cost estimates quoted in euros to pounds based on the year that the cost estimate was quoted in.
Discount rate	All annualised costs are discounted using a discount rate of 3.5% as recommended by the HM Treasury Greenbook for the first 30 years.
Investment lifetime	As this varies between measures, this is described in Appendix A for each measure.
Costs	Estimates are resource / equipment costs and not total implementation costs such as any additional incentives that may be required to encourage the uptake of a particular technology.

2.6 Uncertainties

Annual costs of abatement, incremental emission reductions and cost-effectiveness of abatement measures are calculated from a number of input variables. It is recognised that there can be significant uncertainty in the values of these variables, more specifically;

- **Projected emissions** to 2010 are taken from the NAEI and are governed by uncertainty that is related to the underlying data and assumptions from BERR, DfT, AEA and other organisations regarding activity levels, BAU uptake of measures, efficiency of measures, etc. The impact of uncertainty on the emission projections has been investigated by AEA using risk analysis software. The analysis showed that "*there is only a 1.95% chance that the NOx ceiling will be met in 2010. By 2015, there is a 97.89% chance of meeting the NOx target, which suggests that it is likely that the UK will meet the NOx target 2 – 3 years late*" [8];

- **Measure-specific reduction efficiency** is well defined in some sectors but highly uncertain in others, especially non-technical measures;

- The impact of an abatement measure within a sector is subject to uncertainty due to **variations across the sector** in; size/site specific factors (for instance of a plant), existing technology in place and the lifetime of the measure. In some sectors the variations are well understood but not in others. In addition the impact of an abatement measure within a sector is subject to uncertainty due to **the uptake of**

[8] AEA Energy & Environment (2007): Projected Emission Projections - The results and assumptions of the 2005 air quality pollutant emission projections. A report of the National Atmospheric Emissions Inventory, December 2007.

the measure assumed. For each sector the potential uptake of measures has been determined based on published information available and/or consultation with sector experts. For some scenario analysis various uptakes have been considered;

- **Implementation costs of abatement measures** will vary from plant-to-plant / source-to-source for similar reasons that determine the uptake of measures. Furthermore, for the purposes of the main analysis of this study the 'best estimate' costs have been used in most cases where ranges have been available – introducing further uncertainty when comparing different measures (for instance the best estimate costs of two measures may be in a similar range, although the lower range of one measure may be significantly lower that the other). It should be noted that this report has not considered a premium of prices for putting in place measures in such a short timescale (by 2010). In addition, costs that may be incurred due to the interruption of normal working processes, safety issues that need to be resolved and any other problems that may be encountered have not been taken into account. When available, ranges of cost estimates for the measures considered have been presented in Appendix A to indicate the variability / uncertainty of the estimates.

In the database several non-technical transport measures have been included. For some of these measures (for example, switching freight from road to rail) it has not been possible to fully quantify the impacts and therefore to determine the effectiveness and/or the cost of the measure (although estimates of potential emission reductions have been made where possible). Therefore in some cases, it has not been possible to include these measures in most of the scenario analysis; although these measures could potentially achieve significant NOx reductions (see Appendix A for further details).

3. Scenario Analysis

3.1 Introduction

A range of compliance scenarios have been developed with different combinations of measures to meet the 2010 NOx NEC target, and are described in this Section. The 2010 NOx NEC target is set as 1167kt and this implies that the UK should reduce projected 2010 emissions by 129kt, based on the NAEI projection of 1296kt[9]. However, it should be noted that an uncertainty analysis undertaken by AEA[10] showed that low and high projected 2010 NOx emissions are 1038 and 1582kt respectively.

These scenarios are purely illustrative and have been developed solely for the purposes of this study. They do not represent any government preference regarding implementation of the NECD and a number of other scenarios could equally have been considered, especially those targeting specific sectors.

There are various policy instruments (regulatory and market-based instruments) that could be implemented to encourage the uptake of some of the abatement measures / scenarios considered within this report. It is not within the scope of this study to describe and assess all the various policy instruments.

It must be noted that many measures are incremental measures, that is to say, that the absolute reductions that they may bring if considered individually will be higher than the reductions they may bring if considered in conjunction with other measures. This has been taken into account for the development of the compliance scenarios. Therefore, in some cases total emission reductions quoted may not correspond with the emission reduction figures of each measure when summed. For instance, for the road transport sector one of the scenarios considers selective catalytic reduction (SCR) to be fitted on buses and HGVs, whilst another considers SCR to be fitted only on HGVs, therefore these measures have been considered as incremental measures.

3.2 Scenario 1: Least cost approach

The first scenario considered focuses purely on the cost effectiveness of measures. Measures, that if implemented would result in the UK meeting the NOx NEC, have been selected based on

[9] Projections for 2010 have recently been updated so that 2010 NOx emissions from petroleum refineries are now estimated to be 2kt less than what is presented in this study. Personal Communication with AEA Energy & Environment, 15th May 2008

[10] AEA Energy & Environment (2007): Projected Emission Projections - The results and assumptions of the 2005 air quality pollutant emission projections. A report of the National Atmospheric Emissions Inventory, December 2007.

their cost effectiveness. Figure 3.1 presents the resultant cost curve and Table 3.1 presents the measures rated by their cost effectiveness.[11]

Currently, this scenario considers only the cost-effectiveness of measures in relation to their NOx abatement potential. However a few measures could reduce emissions of more than one pollutant, whilst other measures may reduce one pollutant but increase the emissions of another pollutant(s). Section 4.2 qualitatively describes the impacts of the measures considered for 2010 on other pollutants and GHGs. The impacts that certain measures may have on emissions of other pollutants will be considered in more detail in the second phase of this study, i.e. when measures and scenarios are developed for 2015 and 2020.

[11] Emission and cost data when summed may not agree with totals presented in the table (cumulative costs and emissions remaining) due to rounding errors.

Figure 3.1 2010 NOx Cost Curve

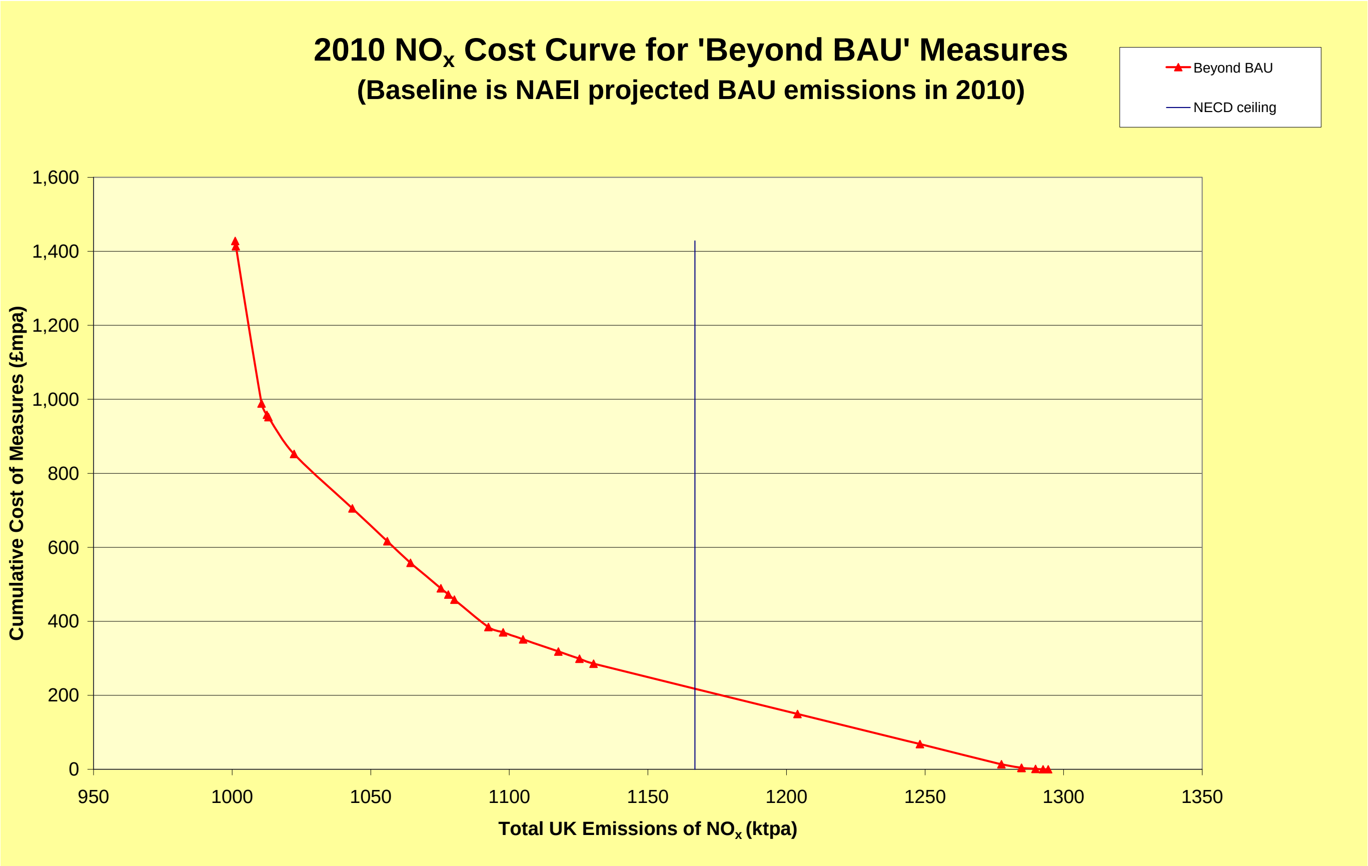

Table 3.1 Measures considered, under the least cost approach, and their cost effectiveness (red line indicates point at which NOx 2010 NEC is achieved)

Sector	Fuel Code	Measure Description	Total Annualised Cost £kpa	Emission reductions of NOx 2010 (kt)	Cost Effectiveness (£/tonne of NOx)	Emissions Remaining (kt)	Total Cumulative Cost (£M pa)
		No measures				1,296	
Road transport	All fuels	Absolute Speed limit enforcement for cars of 70mph on motorways	-25,486[1]	1	0[1]	1294	0
Road transport	Replacing Diesel	Compressed Natural Gas retrofitted to HDVs from 2008 at a rate of 0.4% per year.	-12,622[2]	2	0[2]	1293	0
Cement Sector		SNCR - Scenario: 20% uptake	933	3	345	1290	0.93
Other industrial combustion	Gas	Combustion Modification - Scenario: 20% uptake	3,038	5	601	1285	3.97
Off-road Sources	Gas Oil & Petrol	Further uptake of Stage II controls (by Agriculture - mobile machinery & Industrial off-road mobile machinery) by new engines (2%)	57.9	0.1	954	1285	4.03
Off-road Sources	Gas Oil & Petrol	Early uptake of Stage IIIA controls (by Agriculture - mobile machinery & Industrial off-road mobile machinery) by new engines (15%)	9,628	7	1,338	1278	13.66
Power Stations	Coal	SCR - Scenario: 20% SCR uptake - Opt in	54,392	29	1,848	1248	68.05
Power Stations	Coal	SCR - Scenario: 50% SCR uptake - Opt in	135,980	74	1,848	1204	149.64
Power Stations	Coal	SCR - Scenario: 100% SCR uptake - Opt in	271,960	147	1,848	1130	285.62
Petroleum refineries	All fuels	SCR - Scenario: 20% uptake	13,135	5	2,581	1125	298.75
Petroleum refineries	All fuels	SCR - Scenario: 50% uptake	32,837	13	2,581	1118	318.45
Petroleum refineries	All fuels	SCR - Scenario: 100% uptake	65,673	25	2,581	1105	351.29

Sector	Fuel Code	Measure Description	Total Annualised Cost £kpa	Emission reductions of NOx 2010 (kt)	Cost Effectiveness (£/tonne of NOx)	Emissions Remaining (kt)	Total Cumulative Cost (£M pa)
Road transport	Diesel	Advanced uptake of Euro VI for HDVs	18,818	7	2,620	1098	370.11
Autogenerators & Other industrial combustion	Gas	CM & SCR - Scenario: 10% uptake	14,397	5	2,709	1092	384.50
Road transport	All fuels	HGVs fitted with SCR from 2008 at 4% per annum (approx. 20,000 lorries per annum). Buses assumed to be impacted otherwise	74,202	12	6,052	1080	458.71
Iron and Steel works	All fuels	SCR - Scenario: 20% uptake[3]	13,690	2	6,223	1078	472.40
Domestic households	Gas	New gas fired appliances with tighter NOx emission standards	17,098	3	6,278	1075	489.49
Domestic households	Gas	Further uptake of new gas fired appliances with tighter NOx emission standards	68,391	11	6,278	1064	557.89
Power Stations	Gas	SCR - Scenario: 20% SCR uptake - all sector	58,881	8	7,003	1056	616.77
Power Stations	Gas	SCR - Scenario: 50% SCR uptake - all sector	147,203	21	7,003	1043	705.09
Power Stations	Gas	SCR - Scenario: 100% SCR uptake - all sector	294,407	42	7,003	1022	852.29
Road transport	All fuels	Buses fitted with SCR from 2008 at 20% per annum. HGVs fitted at 4% per annum (approx. 20,000 lorries per annum).	173,632	21	8,076	1013	951.72
Road transport	All fuels	Uptake of Electric-Diesel Hybrid buses replacing existing diesel buses at 1% of fleet per annum (approx. 150 buses per annum)	6,576	1	11,567	1013	958.30

Sector	Fuel Code	Measure Description	Total Annualised Cost £kpa	Emission reductions of NOx 2010 (kt)	Cost Effectiveness (£/tonne of NOx)	Emissions Remaining (kt)	Total Cumulative Cost (£M pa)
Road transport	All fuels	Hybrid electric passenger cars replacing existing stock assumed to be 0.5% of new car sales per annum from 2008 (approx. 50,000 cars per year). This is assuming no incentives are in place. Prices inflated to 2007 but otherwise kept constant.	30,184	2	15,706	1011	988.48
Offshore oil and gas - own gas combustion	Natural gas	Dry Low NOx emission technology - Scenario: 20% uptake	425,183	9	45,817	1001	1,413.67
Road transport	All fuels	AQSR Measure: E - Programme of incentives to increase penetration of low emission vehicles (LEV) from 2008 (note - AQS is from 2006)	14,314	0.2	59,475	1001	1,427.98

[1] Cost-effectiveness is in fact negative (i.e. a cost-saving) due to the potentially significant fuel savings that would be gained from the measure and do not take into account the potential benefits of improvements in safety. It is assumed that the administrative burden of the enforcement would be revenue-neutral. It should be noted that the capital cost for this measure is £694M.

[2] Cost-effectiveness is in fact negative (i.e. a cost-saving) due to the fuel savings associated with switching to CNG. However, it should be noted that the capital cost for this measure is £124M.

[3] It should be noted that the GAINS model unit costs for gas have been applied for all fuel types.

As it can be seen from Table 3.1, in order for the UK to meet the NOx NEC in the most cost-effective manner, abatement measures should target road transport, the cement industry, other industrial combustion (i.e. gas boilers, turbines, and engines) and coal power stations.

For road transport, one of the most cost-effective abatement measure is compressed natural gas (CNG) retrofitted to HDVs and is thought to be feasible for 2010. This measure considers the incentivised conversion of HDVs – both HGVs and buses – to run on compressed natural gas (CNG) instead of diesel. The measure assumes 0.4% of existing HDVs are converted to run on CNG per year, or approximately 2,000 vehicles total annually. Overall, this measure has been estimated to reduce NOx emissions by 1.8kt with a total annual saving of approximately £13M due to the fuel savings associated with switching to CNG, although the capital cost for this measure is considerable (£124M). Furthermore, another cost-effective abatement measures is the absolute speed limit enforcement for cars of 70mph on motorways. Overall, this measure has been estimated to reduce NOx emissions by 0.6kt with a total annual saving of £25.5M due to the fuel savings, although the capital cost for this measure (i.e. comprehensive blanket coverage of SPEC speed cameras) is considerable (£694M).

SNCR is considered to be more cost-effective than SCR for the cement sector. There are currently 15 cement plants in the UK (BCA, July 2007) of which 6 plants are thought to have SNCR (EC, 2007). Hence, the maximum additional uptake rate across the sector is estimated to be 60%, assuming each plant is roughly of a similar size. For the purposes of this scenario the additional uptake of SNCR has been assumed to be 20% across the sector. As this sector only contributes by approximately 2% to total emissions, variations for the uptake rate were not considered for this scenario. Overall, this measure has been estimated to reduce NOx emissions by 2.7kt with a total annual cost of £0.9M.

Combustion modification has been considered as an abatement measure targeting other industrial combustion of gas.[12] This measure may in practice be difficult to implement by 2010 due to the large number of sites that this sector is thought to encompass. For the purposes of this scenario the beyond BAU uptake of combustion modification has been assumed to be low, i.e. 20%. As this sector contributes approximately 7% to total emissions and abatement measures may be difficult to implement, variations for the uptake rate were not considered for this scenario. Overall, this measure has been estimated to reduce NOx emissions by 5.1kt with a total annual cost of £3M.

The off-road measure relates to the early additional uptake of Stage IIIA controls and the further additional uptake of Stage II controls by new engines. It should be noted that disaggregated emission and activity data have not been provided for this sector within the timescales of this interim report. The projected emissions for this sector and the efficiency of the proposed measures are very uncertain, mainly because of uncertainty over the BAU uptake of the measures. Overall, the two measures (Stage II controls and Stage IIIA controls) have been estimated to reduce NOx emissions by 0.1kt and 7kt with a total annual cost of £0.06M and £9.6M respectively.

[12] Other industrial combustion is thought to include combustion in industries such as chemicals, rubber and plastics, non-ferrous metals, food and drink, minerals (e.g. bricks, glass and plaster), textiles, electrical and mechanical engineering, paper, printing and publishing, and other sources not included elsewhere.

SCR has been considered as an abatement measure targeting coal fired power stations. Table 3.1 presents three SCR scenarios (i.e. 20%, 50% and 100%) of beyond BAU SCR uptake from coal fired power stations that are opted in to the Large Combustion Plant Directive. In order for the UK to meet the NOx NEC target, the UK should reduce projected 2010 emissions by 129kt. All the measures that are shown to be more cost-effective than SCR for coal power plants, can achieve emission reductions of only 17kt. Therefore, 112kt of NOx would need to be reduced from coal fired power stations, in order for the UK to meet the NOx NEC target by implementing the most cost-efficient measures only. This equates to a 76% uptake of SCR by 2010 from plants that are opted in under the LCPD. Overall, a 76% uptake of this measure by opted-in coal fired plants[13] has been estimated to have a total annual cost of £207M[14]. However, such an uptake is considered unrealistic by 2010 (as discussed in Chapter 3.4) due to time constraints.

If a more realistic uptake of SCR is considered for coal fired power stations, then additional measures may be required for the UK to meet the NOx NEC, such as SCR for combustion in petroleum refineries, iron and steel works and gas fired power stations, as well as other measures for the domestic sector and road transport. SCR installation in power plants is further discussed in chapter 3.4.

Table 3.2 presents the abatement measures considered under the least cost approach with their associated costs as well as the emission reductions that may be realised by 2010. Under this scenario it has been estimated that the UK could meet the NOx NEC for a total annual cost of £220M.[15]

[13] This is equivalent to a 55% uptake of SCR from all coal power plants.

[14] It is important to note that SCR for coal-fired power stations is assumed to be BAU from 2016 onwards in order to comply with the tighter NOx ELVs in the LCPD. Under this assumption the costs for the technology would be incurred by some coal-fired power plants by 2016.

[15] If the negative total annualised costs for the two road transport measures that have significant fuel savings were included the total annualised cost of the least cost scenario would be £182M.

Table 3.2 2010 emission reductions and associated costs under the least cost approach

Sector	Abatement measure	Total annualised costs (£k per year, 2007 prices)	Emissions reduction of NOx in 2010 (kt)
Road transport	Absolute Speed limit enforcement for cars of 70mph on motorways	-25,486[1]	1
Road transport	Compressed Natural Gas retrofitted to HDVs from 2008 at a rate of 0.4% per year.	-12,622[2]	2
Cement Sector	SNCR - Scenario: 20% uptake	933	3
Other industrial combustion - Gas	Combustion Modification - Scenario: 20% uptake	3,038	5
Off-road Sources	Further uptake of Stage II controls (by Agriculture - mobile machinery & Industrial off-road mobile machinery) by new engines (2%)	57.9	0.1
Off-road Sources	Early uptake of Stage IIIA controls (by Agriculture - mobile machinery & Industrial off-road mobile machinery) by new engines (15%)	9,628	7
Coal fired power stations	SCR - Scenario: 20% SCR uptake - Opt in	206,689	112
	TOTAL	220,346[3]	129

[1] Total annualised costs are negative (i.e. a cost-saving) due to the potentially significant fuel savings that would be gained from the measure and do not take into account the potential benefits of improvements in safety. It is assumed that the administrative burden of the enforcement would be revenue-neutral. It should be noted that the capital cost for this measure is £694M.

[2] Total annualised costs are negative (i.e. a cost-saving) due to the fuel savings associated with switching to CNG. However, it should be noted that the capital cost for this measure is £124M.

[3] Total costs exclude potential fuel savings from two transport measures (i.e. negative costs). If these were included the total annualised cost for road transport would be £182M.

3.3 Scenario 2: Equal reduction approach

An alternative scenario has been developed that assumes an equal percentage emission reduction in all sectors considered in this study. For the UK to meet the NOx NEC, it is estimated that 10% of total NOx emissions should be abated by 2010. For the sectors considered in this study, this equates to approximately a 13% reduction in NOx emissions per sector. Table 3.3 presents the abatement measures considered under the equal reduction approach with their associated costs as well as the emission reductions they could achieve by 2010.

Table 3.3 2010 emission reductions and associated costs under the equal reduction approach

Sector	Abatement measure	Total annualised costs[2] (£k per year, 2007 prices)	Emissions reduction of NOx in 2010 (kt)
Coal fired power stations	16% SCR uptake - opted in[1]	43,785	23.7
Gas fired power stations	16% SCR uptake - all sector	47,400	6.8
Petroleum refineries	15% SCR uptake	10,048	3.9
Offshore oil and gas	Own gas combustion: 15% DLE uptake	321,013	7.0
Road transport	All measures (assuming 25% of buses and 6.5% of HGVs fitted with SCR per year) [2]	413,036	51.1
Cement Sector	22% SNCR uptake	1,003	2.9
Iron and Steel works	17% SCR uptake	11,294	1.8
Other industrial combustion	26% CM uptake	3,980	6.6
Domestic households	19% uptake of gas fired appliances with tighter NOx emission standards	66,681	10.6
Off-road Sources	26% of early uptake of Stage IIIA	16,995	12.7
Autogenerators	16% CM & SCR uptake	5,615	2.1
	TOTAL	**940,851**	**129**

[1] This is equivalent to a 12% uptake of SCR from all coal power plants.

[2] Costs exclude potential fuel savings from two transport measures (i.e. negative costs). If these were included the total annualised cost for road transport would be £375M.

From Table 3.3 it can be concluded that if all of these measures as defined above were to be taken forward the UK would meet the NOx NEC with a total annual cost of approximately £941M. [16]

For road transport, the cumulative NOx emission reductions that could be achieved if all measures were considered as defined in this scenario are 51.1kt. For the development of this scenario two of the transport measures have been adjusted in order to achieve a 13% reduction across the sector. These measures assume HGVs and buses are fitted with SCR at higher uptake rates, i.e. 6.5% and 25% per annum respectively (assuming the uptake starts in 2008). The assumed uptake of SCR for HGVs and buses is considered very high, and it may be, in practice, difficult or even unfeasible to implement. Finally within the measures included in this scenario for the transport sector, emission reductions from the shift in HGV vehicle km travelled from road to rail has also been considered, although the costs of this measure are not presented in the total costs of the scenario, as it has not been possible to quantify this at this stage.

[16] If the negative total annualised costs for the two road transport measures that have significant fuel savings were included the total annualised cost of the equal reduction scenario would be £903M

The measure considered for domestic combustion assumes about 19% beyond BAU uptake of gas fired appliances with tighter NOx emission standards. The natural replacement rate of boilers is estimated to be between 5-10% per annum, from which a % may comply with the tighter NOx emission standards. About 7 million boilers are thought to be over 15 years old. The slow take up of condensing boilers is due to the reluctance of consumers to pay more, combined with resistance of installers and the difficulty of installing condensing boilers in certain dwellings[17]. This measure is considered technically feasible, but may be in practice difficult to implement. Approximately 10.6kt of NOx emission reductions could be achieved by this measure for the residential sector.

The off-road measure relates to a 26% early additional uptake of Stage IIIA controls by agricultural and industrial off-road mobile machinery in order to achieve a 12.7kt emission reduction of NOx. However, such an uptake rate is not considered realistic by 2010, especially with regards to constant speed engines.[18] It should be noted that disaggregated emission and activity data have not been provided for this sector within the timescales of this interim report. The projected emissions for this sector and the efficiency of the proposed measures are very uncertain, mainly because of uncertainty over the BAU uptake of the measures.

3.4 Scenario 3: Power sector approach

An additional scenario has been developed, targeting the power sector only. Two variations of this scenario for power stations (coal and gas fired only) are presented in order to give a better insight to the different options that could be developed to meet the 2010 NOx NEC (the UK is projected to exceed its 2010 NOx emission ceiling by 129 kt), if emission reductions were only to be incurred by the power sector. The different scenario variations that have been developed for the power sector for 2010 are as follows:

- A sufficient uptake of SCR for opted in coal fired and all gas fired power stations in order to achieve a reduction of 129 kt;
- A sufficient uptake of SCR for opted in coal fired power stations only (excluding gas fired power stations) to achieve a reduction of 129 kt.

The first scenario variation, which considers opted in coal fired and gas fired power stations to achieve reductions of 129kt, would incur annual costs of the order of £385M. In order to achieve these emission reductions an SCR uptake of 68% across opted-in coal fired and gas fired power plants (for the coal fired sector this refers to a 49% across all coal fired power plants, both opted in and opted out) would be needed[19].

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[17] Available at:
http://www.energysavingtrust.org.uk/uploads/documents/aboutest/Potential_market_for_micro_CHP_2002.pdf

[18] Under the NRMM Directive constant speed engines placed in the marker are required to meet the standard by the 31st of December 2009 (with the exception of constant speed J engines of a power output 27kW≤P<75kW that are required to meet the standard by the 31st of December 2010).

[19] The % uptakes for the different fuels i.e. coal or gas fired, have been calculated based on the waste gas flow rates of the plants.

For the other scenario variation that considers only opted in coal fired power stations to achieve 129kt of NOx emission reductions, a higher SCR uptake across the coal fired sector would be needed i.e. 63% (or 88% of opt-in only coal fired power plants), but the total annual costs would be lower, about £240M.

Table 3.4 presents the data for the two scenario variations described above. It is important to note that SCR for some coal-fired power stations would be BAU from 2016 onwards in order to comply with the tighter NOx ELVs in the LCPD. Therefore the capital costs for fitting SCR would be incurred by some coal-fired power plants by 2016 (i.e. those that are opted-in under the ELV approach under the LCPD, and some under the NERP approach under the LCPD), although there would clearly be an additional cost of bringing forward this investment. Furthermore, an additional operating cost would be incurred up to 2016.

SCR is already currently considered as BAU for coal fired power stations in several Member States. Furthermore, in Germany, for example, upgrading of *existing* SCR units at coal-fired power stations is now being considered as a measure to comply with the NECD.

Table 3.4 2010 NOx emission reductions and associated costs for the electricity supply industry using the JEP (2001) SCR cost data

Scenario	Fuel	Abatement measure	Abatement efficiency (%)	Future uptake of measure across sector % (for 2010)[3]	Lifetime of measure, years	Reduction in 2010 emissions (kt/annum)	Capital Costs (£k, 2007 prices)	Annualised Capital Costs (£k)	Annual operating costs (£k, 2007 prices)	Total annualised costs (£k per year, 2007 prices)[3]
SCR uptake - Opt in coal & all gas	Coal	SCR	80%	49%[1]	15	100	1,083,630	94,086	90,846	184,932
	Gas	SCR	80%	68%	15	29	1,766,751	153,398	46,798	200,197
	TOTAL					**129**	**2,850,381**	**247,485**	**137,645**	**385,129**
SCR uptake - only coal opt in	Coal	SCR	80%	63%[2]	15	129	1,402,345	121,759	117,566	239,324[5]

Note: SCR costs are taken from the JEP (2001) report

[1] 68% uptake of SCR from all coal power plants that opt in for the LCPD

[2] 88% uptake of SCR from all coal power plants that opt in for the LCPD

[3] Appendix A presents a range of costs for opted in coal fired power plants. For this scenario the total annual cost range is £93M- £281M.

The annual costs for SCR instalment across the power sector presented in the previous table applied SCR data that were taken from the JEP (2001) report which focused on the electricity supply sector of England & Wales[20]. Costs for the application of SCR to power stations are also presented in the LCP BREF document (European Commission, 2006), data provided by the AEP and other sources, which are discussed in further detail in Appendix A.1. For the development of the scenarios; the data from the JEP document have been used as a baseline figure as it is primarily focussed on UK coal power stations and is within the range of the other figures. In practice there is likely to be at least a +/- 30% uncertainty around these figures for actual installations. See Appendix A.1 for more details.

Aside from cost implications, there is a significant issue regarding the feasibility of fitting SCR within the 2010 NOx timescales. Relevant points include:

- Power plant operators would not want to shut down their power plant unnecessarily in order to install SCR. However, large combustion plants have to stop operations for statutory inspections every 3 years, and hence, the preferred option would be to install SCR during the plants normal outage period. Some power plants have agreed a normal outage period every 4-5 years. If fitting SCR offers considerable benefits to plant operators then they may decide to bring the outage period forward. Typically the normal outage of a plant lasts between 4-10 weeks, and if the majority of the new plant has been built by the outage period, it may be possible to connect the existing system with the new equipment within 5-8 weeks, thus avoiding the need for any additional outage. However, AEP has highlighted that an additional outage period of 1 to 3 months may be required (especially for 'high dust' SCR and that this additional outage period could cost an additional £15m per GW capacity);

- The installation of SCR may require a planning consent (usually granted by BERR). If consent is required then the period for obtaining this should be taken into account. Typically, 3-4 months are required for the preparation of a planning application, and an additional 4 months is required for statutory consultation. The period for the determination of the consent is at the discretion of the competent authority and this could be between 1 to 12 months. If this scenario is to be considered as a possible option to meet the 2010 NOx NEC, then Defra should consult power plant operators as soon as possible to establish whether some plants have already started the process of the planning application. This could significantly reduce the time needed to fit SCR in an operational plant;

- The time required for the procurement of the technology needs to be taken into account, and this is typically around 6 months.[21] If SCR is to be fitted as soon as possible this should be undertaken in parallel with the planning application process.

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[20] JEP (2001) Assessment of England and Wales electricity sector BATNEEC for NOx

[21] A technology provider indicated that current supply capacity would enable the UK's coal-fired power stations to be fitted with SCR catalysts with completion in 2010. However, it was recognised that the availability of engineering and erection staff and subcontractors is already limiting shorter implementation periods.

However, procurement is not expected to be completed before planning consent has been granted[22];

- Approximately 12 to 24 months are required to build the new SCR unit.[23] However it should be noted that construction in an operational power station may be challenging, for instance there may be space limitations or safety issues to overcome. In fact, space and practicality on some sites may make it very difficult to fit in systems on some units without major relocation of plant items i.e. air heaters, ducting, fans, new fans required for additional pressure drop requirement etc. Such issues will have implications on timescales and costs;
- If a lot of companies are forced to fit SCR within the next 3 years this could result in constraints in the supply market.

AEP estimates that the first SCR unit at a power station could be operational by the end of 2011, although this was considered an optimistic scenario and a more realistic timing for that would be 2012.[24] For this to be feasible AEP highlighted that the power company's board level consent would be required by mid 2008, the contractor would need to be identified by the end of 2008, the planning consenting would need to be complete by mid 2009, the Front End Engineering Design (FEED) study would need to be complete by the end of 2009, the site enabling works and pre-outage works would need to be complete by early 2010, so that connection and commissioning is achieved by mid / end of 2011.

After the first SCR unit is installed, the remaining SCR units at a plant could be installed in consecutive years, one SCR unit for each year i.e. if the first SCR unit was fitted in 2011 the fourth could be fitted in 2014 (or 2015 if the first unit was fitted in 2012). AEP highlighted that it is unrealistic that full SCR instalment on all ESI capacity will be completed by 2014 given contractor availability (and a 6-unit conversion in the case of one power plant).

In conclusion, a scenario of approximately 20% SCR uptake across opted in coal fired and all gas fired power stations is more realistic for 2012 than 2010, if instalment of this abatement technique was scheduled during normal annual overhaul periods, with the costs and emission reductions presented in section A.1.3. Further NOx emission reductions than those presented in section A.1.3 for a 20% SCR uptake could be achieved by increasing load factors to the SCR unit of the plant and reducing load factors of the unabated units.

22 A technology provider indicated that six to twelve months may have to be allowed for investment decisions, financing and tendering procedures before a contract is awarded.

23 This has been confirmed by a technology provider.

24 Personal Communication with AEP (Association of Electricity Producers), 16th April 2008.

4. Conclusions and Recommendations

4.1 Conclusions

The 2010 NOx NEC target is set at 1167kt and the projected BAU 2010 emissions, according to the NAEI projections[25], imply that the UK needs to reduce emissions by 129kt[9]. For this interim report a range of compliance scenarios have been developed with different combinations of measures to meet the 2010 NOx NEC target.

Least cost scenario

The least cost scenario to achieve the 2010 NOx NEC target, in the most cost-effective manner, would target road transport, the cement industry, other industrial combustion (i.e. gas boilers, turbines, and engines) and coal power stations. The majority of the abatement measures under this scenario are thought to be technically feasible for 2010 although there may be some issues concerning the practical implementation of certain measures. For example, targeting other industrial combustion may in practice be difficult due to the high number of relatively small units which may need to be modified. Furthermore, the NOx emission reduction burden falls considerably on the power sector and it is not likely to be possible to fit SCR on coal fired power stations by 2010, with the first units likely to be possible to be fitted by 2012. It is worth noting that SCR for some coal fired power stations is expected to be required by 2016 in order to comply with the tighter NOx limits under the LCPD, so the additional costs associated with SCR would only apply during the period for which the implementation of SCR was brought forward (i.e. by 6 years).

Equal reduction scenario

The equal reduction scenario assumes an equal percentage emission reduction is achieved in all sectors considered in this study equating to a reduction of approximately 13% in these sectors. As with the least cost scenario, the majority of the abatement measures under this scenario are thought to be technically feasible for 2010 although there may be some issues concerning the practical implementation of certain measures. In particular, the road transport measure that assumes the retrofit of SCR to HGVs and buses at 6.5% and 25% per annum, respectively, is ambitious and it may therefore be difficult to implement such uptakes by 2010 in practice. A similar issue may also arise for the measure considered for domestic combustion that assumes a 20% replacement of old boilers by gas fired appliances with tighter NOx emission standards. The measure considered for the off-road sector, i.e. the early uptake of Stage IIIA controls by agricultural and industrial off-road mobile machinery, assumes an additional uptake that may in practice not be realistic by 2010 and is highly uncertain due to a lack of disaggregated data available for the sector within the timescales of this report.

[25] Provided by AEA Energy & Environment, 12th November 2007

Power sector scenario

The power sector scenario has two variations in order to achieve the 2010 NOx NEC target assuming that only the power sector would make the necessary emission reductions. The first scenario variation assumes a sufficient uptake of SCR for opted in coal fired and all gas fired power stations in order to achieve a reduction of 129 kt; whilst the second scenario variation assumes a sufficient uptake of SCR for opted in coal fired power stations only (excluding gas fired power stations) in order to achieve the target emissions reduction. The first scenario variation would result in annual costs of the order of £385M assuming an SCR uptake of 49% across coal fired (68% of opt-in coal fired power plants) and 68% across gas fired power stations. For the second scenario variation a higher SCR uptake across the coal fired sector would be needed i.e. 63% (or 88% SCR uptake from opt-in coal fired power stations), whereas the total annual costs would be lower, about £239M, suggesting that it would be more cost effective to target the larger opted-in coal fired power stations. It should be noted that SCR for some coal fired power stations would be BAU from 2016 onwards in order to comply with the tighter NOx ELVs in the LCPD. Therefore the capital costs for fitting SCR would be incurred by some coal-fired power plants by 2016.

The various limitations in fitting SCR by 2010, described in Chapter 3.4, should be taken into account when considering this scenario. In particular, it is estimated that SCR could be fully installed in an operational plant at the earliest by 2011.

Overview

Table 4.1 summarises the three scenarios considered and their associated costs and 2010 emission reductions.

Table 4.1 2010 emission reductions and associated costs of the scenarios considered

Scenario	Emissions reduction of NOx in 2010 (kt)	Total annualised costs (£M per year, 2007 prices)
Least cost scenario	129[3]	220[1]
Equal reduction scenario	129[3]	941[1,2]
Power sector scenario[3]	129[3]	240 - 385

[1] This cost does not include negative total annualised costs for two road transport measures that have significant fuel savings. If these were included the total annualised cost of the least cost and equal reduction scenario would be £182M and £903M respectively.

[2] These costs do not include the costs of the measure that considers the shift in HGV vehicle km travelled from road to rail, as this has not been quantified.

[3] It is estimated that emission reductions from power stations could be achieved from 2011 at the earliest, although 2012 is more likely.

As all scenarios are assumed to achieve equal NOx reductions the associated benefits are the same for all scenarios and are presented in Table 4.2.

Table 4.2 Associated benefits of the scenarios considered

Source	Damage cost function (NOx damage £ per tonne emission)	Total annualised benefit for a NOx emission reduction of 129kt (£M per year)
IGCB (2007) based on a 6% PM concentration response function[26]	681 - 993	88 - 128
Central estimate recommended by IGCB[27]	964	124
CAFE[28]	Mid-point 4,756 (2,669 - 6,843)[29]	Mid-point 614 (344 - 883)

It should be noted that there are significant differences in the damage costs developed by the IGCB and CAFE. Total benefits outweigh the costs of the least cost and power sector scenarios when the CAFE damage cost functions are applied, whilst total costs are higher for all scenarios than the benefits when the IGCB values are applied. It is also worth noting, that if costs for the installation of SCR at power plants are based on the LCP BREF as shown in Appendix A, then, total benefits outweigh costs, independent of which damage cost functions are used.

It should be recognised that these quantified benefits exclude benefits due to reductions in emissions of other pollutants. Such benefits would need to be taken into account before drawing conclusions on the net costs of the measures considered in this report.

Annual costs of abatement, incremental emission reductions and cost-effectiveness of abatement measures are each key parameters in defining the compliance scenarios and their values are calculated from a number of input variables. It is recognised that there can be significant uncertainty in the values of these variables, and hence, in the compliance scenarios developed, more specifically; in projected BAU emissions to 2010; measure-specific abatement efficiency; uptake of measures; and implementation costs of abatement measures (described further in section 2.6).

4.2 Considerations/Recommendations

Multi-Pollutant Impacts

The focus of this interim report has been on possible ways in which the 2010 NOx NEC could be achieved in the UK. The impacts of potential measures on pollutants apart from NOx have not been quantified as this is not within the scope of this study. However, when considering measures to take forward for the 2010 NOx NEC it is important to consider the impacts that

[26] IGCB (2007) *An Economic Analysis to inform the Air Quality Strategy*, Updated Third Report of the Interdepartmental Group on Costs and Benefits, July 2007.

[27] Personal communication with Defra, 18/01/08

[28] AEA (2005) Damages per tonne emission of PM2.5, NH3, SO2, NOx and VOCs from each EU25 Member State (excluding Cyprus) and surrounding seas, AEA Technology Environment. March 2005.

[29] 2007 Exchange rate assumed to be 0.6843 based on the ECB Statistical data warehouse.

certain measures may have on emissions of other pollutants as well as changes in fuel efficiency/consumption. The impacts that certain measures may have on emissions of other pollutants will be considered in more detail in the second phase of this study, i.e. when measures and scenarios are developed for 2015 and 2020.

Table 4.3 indicates the impacts of the measures considered for reducing emissions of NOx in 2010 on other pollutants and GHGs.

Table 4.3 Impacts on other pollutants of measures considered for reducing emissions of NOx in 2010

Measures	SO_2	PM	VOC	NH_3	CO_2	CH_4	N_2O	CO
Selective Catalytic Reduction (SCR)				+[1]	+[2]		+	-
Dry Low NOx emission technology								
Gas fired appliances with tighter NOx emission standards (more efficient boilers)					-[3]			
Selective Non-Catalytic Reduction (SNCR)				+[1]	+[2]		+	-
Combustion Modification[5]								
Further uptake of Stage II controls		-	-			-		-
Early uptake of Stage IIIA controls		-	-			-		-
Speed limit enforcement[6]	-	-	-		-			-
Transfer of freight from road to rail	-	-	-		-			-
Retrofitting SCR to HDVs				+[4, 1]	+[2]			
Retro-converting HDVs to use Compressed Natural Gas	-	-	-		-	+		
Replacement of existing vehicles with hybrids	-	-	-		-		-	-
Euro VI standard for HDVs (including early uptake)[7]	-	-	-	+	+[2]		+	-
Low emission vehicles (LEVs)	-	-	-	-	-	-	-	-

[1] Can result in ‘slippage’ (i.e. emissions to the atmosphere) of the reagent used (ammonia or urea)

[2] Due to increased fuel consumption

[3] Due to decreased fuel consumption

[4] Dependent on what reductant is used

[5] Dependent on how combustion modification is defined

[6] May also lead to significant safety benefits in terms of a reduced incidence or severity of accidents

[7] Depends on what technology is used to meet the standard (for the purposes of this table it has been assumed that SCR would be used and not exhaust gas recirculation)

In addition to the direct impacts of the measures to other pollutants, there are indirect impacts that should be taken into account. More specifically, fitting SCR to coal (and gas) power stations with limited life remaining could result in the extended operation (and at higher load factors) of high CO_2 emitting power stations, in order to recover the SCR costs.

Impact on local air quality

Measures considered in the scenario analysis above will also impact on local air quality and associated human exposure. For instance, measures targeting road transport and domestic combustion may reduce concentrations of air pollutants in urban areas with high population density where most exceedances of air quality objectives occur. Reductions of emissions from autogenerators and other industrial combustion could also contribute towards reducing ambient air concentrations and human exposure, depending on the location of sites. In contrast, measures to reduce emissions from power stations, which tend to be located away from densely populated urban areas and release their emissions from tall chimneys, will have a relatively limited impact on reducing exceedances of air quality objectives and improving local air quality.

Policy instruments

There are various policy instruments (regulatory and market-based measures) that could be implemented to encourage the uptake of some of the abatement measures considered within this report. It is not within the scope of this study to describe and assess all the various policy instruments. However, some that have been implemented or are being considered by other Member States to comply with the 2010 NOx NEC and/or future targets that could be considered in the UK are described below:

- Emissions trading for NOx has been introduced in the Netherlands for a range of industrial sectors and is currently being considered in other Member States (for example, Poland). The UK has already developed and implemented an emissions trading scheme for LCPs as a way of achieving compliance with the LCPD (as part of a National Emission Reduction Plan); this came into force for existing plants at the start of 2008. This could potentially be developed further to reduce emissions beyond that required by the LCPD and/or expanded to other industrial sectors such as iron and steel;
- Other market based instruments, such as grants, taxes and/or feebate schemes could be introduced to incentivise the uptake of abatement measures, such as SCR. For instance a NOx charge has been implemented in Sweden for the energy sector (currently €4.3 per kg of NOx) and it acts as an incentive for improving efficiency as all revenue, minus the costs of administration, is returned to participating plants. Sweden plans to increase the charge to over €5 per kg of NOx and extend it to more sectors in order to further reduce NOx emissions.

Recommendations

As a result of the work undertaken for this interim report, the following recommendations have been drawn for future work:

- To undertake a detailed assessment of SCR costs, in particular for the power sector;
- To consider in more detail issues on implementation of measures within the 2010 timescales;

- To undertake a competitiveness analysis for a selection of measures/sectors;
- To undertake an assessment on the affordability of measures. For instance some measures have a low total annualised cost, however this is not an indication of the affordability of the measure as they may have high capital costs that are not reflected in the total annualised cost due to significant operating savings;
- To undertake a detailed assessment of potential policy instruments that could encourage the uptake of some of the measures considered in this report;
- To critically review the emission projections and the underlying assumptions; and
- To consider implications to this analysis due to uncertainties in the underlying NAEI emissions projections.

Appendix A
Sector Analysis

A.1. Electricity Supply Industry

A.1.1 Sector Profile

Table A1.1 presents the 2010 NOx emissions for the UK electricity supply industry developed by AEA[30], based on the BERR UEP 30 forecasts (DTI, 2007) and the 2005 National Atmospheric Emission Inventory (NAEI). It is clear that the key sources of NOx emissions are coal and natural gas fired power stations, hence the analysis for the electricity sector for 2010 has focused on these emission sources.

Table A1.1 2010 NOx emissions for UK electricity supply industry

SnapID	Source Name	Activity Name	Projection Year	Emission (kt)
10101	Power stations	Coal	2010	226.84
10104	Power stations	Natural gas	2010	35.34
10101	Power stations	Fuel oil	2010	6.56
10102	Power stations	MSW	2010	6.34
10105	Power stations	Landfill gas	2010	1.90
10102	Power stations	Gas oil	2010	1.34
10101	Power stations	Waste oils	2010	1.13
101	Power stations	Poultry litter	2010	0.98
10105	Power stations	Sewage gas	2010	0.30
101	Power stations	Straw	2010	0.27
10101	Power stations	Sour gas	2010	0.25

A.1.2 Business as Usual Policies and Abatement Techniques

The Updated Energy Projections 30 (UEP 30) have been developed in response to the Government's Energy White Paper published in May 2007 (DTI, 2007). These projections have taken into consideration a number of assumptions for the electricity supply industry (AEA, 2007); the ones relevant to year 2010 are presented below:

[30] Personal Communication with AEA Energy & Environment, 12th November 2007

- Between 2005 and 2010, 2.5GW of existing capacity is assumed to close, of which 1.5 GW is assumed to be nuclear and 0.5GW coal;
- Plant operations are constrained by environmental limits. Where FGD is not available, a coal plant opted out under the Large Combustion Plant Directive (2001/80/EC) (LCPD) requirements is assumed to operate on low sulphur coal. New coal-fired plants are assumed to be fitted with SO_2 and NOx clean up equipment (AEA, 2007);
- It is assumed that nearly all coal fired power stations remaining in operation in the latter half of this decade will have installed an over-fire air (OFA) system or achieve equivalent NOx emission reductions to this abatement technique;
- Renewables capacity is assumed to rise in accordance with the government's commitment to ensuring that the contribution of renewables to the total generating mix increases over time. The assumption behind this increase is based on modelling conducted by Oxera for the Energy White Paper[31];
- Imports of electricity are assumed to increase. Similarly the availability of new interconnection capacity allows for increased export levels in the future.

The LCPD came into effect from 1st January 2008 for existing plants. However the more stringent NOx emission limit values of 200 mg/Nm^3 for solid fuel power stations > 500MWth will only come into effect from 1st January 2016 onwards. Power stations are not assumed to take measures to meet these ELVs until then.

The other key policy affecting NOx emissions from the power sector is the IPPC Directive. Under this Directive, the compliance date for existing installations to operate in accordance with BAT-based permit conditions was 30 October 2007. IPPC permits for power stations have improvement plan conditions related to identifying options for reductions in emissions and proposing a timetable for improvements where practicable. It has been assumed that IPPC implementation in the UK would not require NOx measures more stringent than LCPD for coal power stations (500 mg/Nm^3 from 2008 to 2015), i.e. would not require SCR (until 2016). However, from studies undertaken for the European Commission as part of the review of the IPPC, it appears that other Member States are implementing IPPC for the power sector in a more stringent way, setting permit conditions more consistent with the BREF BAT Associated Emission Levels (AELs), which for NOx for coal power stations are up to 200 mg/Nm^3. Achieving this level would require SCR or equivalent techniques.

A.1.3 Beyond Business as Usual

Additional measures for beyond BAU commitments for the electricity supply industry have been considered for coal and gas fired power stations, as they are the dominant NOx emission sources for year 2010 (see Table A1.1).

[31] Oxera, Reform of the renewables obligation – what is the likely impact of changes? (2007).

A.1.3.1 Abatement Techniques

The beyond BAU measure considered for coal and gas fired power stations for year 2010 is Selective Catalytic Reduction (SCR).

A.1.3.2 Methodology/Assumptions

AEA[32] provided the underlying data for the projections of UK NOx emissions for 2010, 2015 and 2020 (AEA, 2007) associated with the electricity supply industry. Coal fired power stations are presented at a site level, hence future fuel use and emissions are calculated per site, whereas gas and oil fired power stations are presented at a more aggregated level for different areas i.e. England & Wales, Scotland and Northern Ireland. The analysis has focused on the main sources of NOx emissions i.e. coal and natural gas (see Table A1.1).

It has been assumed that plants that opt in to comply with the ELVs will fit SCR by 2016 as BAU, whilst plants that opt in to comply with the NERP may fit SCR by 2016 as BAU (not all plants in the NERP would need to fit SCR if required reductions are achieved with load factor management, etc).

Capital and operating costs

Costs based on JEP (2001) report on NOx abatement

The JEP report (2001) on "Assessment of England & Wales electricity sector BATNEEC for NOx" describes this abatement technique in detail, including lifetime, abatement efficiency and capital and operating costs (see Table A1.2). The cost data are separated into capital, fixed operating and variable operating costs and different costs apply to coal fired and gas fired power stations (see Table A1.2).

Table A1.2 Information on SCR (JEP, 2001) [1]

Measure	Capital cost (£/kWe)	Fixed operating cost (£/kWe/year)	Variable operating cost (£/MWhr) [2]
SCR [3]	65	2.6	0.6
CCGT SCR retrofit [4]	80	1.9	0.04

Note 1: Cost prices are for year 2001

Note 2: The JEP report (2001) gives variable operating costs in £ / MWhr – this has been assumed to be MWhr electrical

Note 3: These costs are considered for fitting SCR to coal fired power stations. Fixed operating costs include catalyst replacement costs and variable operating costs include ash sales lost and ammonia costs

Note 4: Fixed operating costs include production losses due to loss of availability of the plant during installation of the SCR unit and variable operating costs include ammonia costs

32 Personal Communication with AEA Energy & Environment, 14th November 2007

As presented in Table A1.2, capital, fixed operating and variable operating costs are summarised in the JEP (2001) report. The DUKES (BERR, 2007) report was used to identify installed capacity (in MWe) and to calculate load factors for coal and gas fired power stations. For coal fired power stations where 2010 fuel use was given per site in the AEA data, site specific load factors were estimated using the total annual energy input calculated from the 2010 fuel use and the maximum total energy input per annum based on installed capacity for each site (the data on installed capacity are taken from the DUKES report). The site specific load factors ranged from 26% to 62%; the lowest load factors i.e. < 30% were for coal fired plants that are opting out of the LCPD requirements i.e. they are opting for the Limited Life Derogation of 20,000 operational hours under Article 4 (4) of the LCPD.

For gas fired power stations a load factor of 62.5% is assumed for CCGT plants using the data provided in the DUKES report for period 2002 – 2006 (BERR, 2007; Chapter 5 Electricity).

Table A1.3 summarises the 2010 NOx emission reductions and associated costs for the electricity supply industry for opted in coal fired and all the gas fired power stations. Opted out coal fired power stations i.e. opting for the limited life derogation, have not been considered since it would be unrealistic for these power stations to fit SCR, since they are only going to operate a maximum of 20,000 hours according to the LCPD during the period 2008 – 2015 before they close down. Different uptakes of SCR have been investigated, including 100%, 50% and 20% as shown in the table below. The costs shown below have used SCR cost data taken from the JEP (2001) report.

Table A1.3 Summary of SCR measures and costs for the electricity supply industry for 2010 (using JEP 2001 cost data)[6]

Measure - SCR	Emission reduction efficiency (%) of measure	Future uptake of measure % (for 2010)	Reduction in 2010 emissions (kt)	Capital Costs (£k, 2007 prices)	Annualised Capital Costs (£k)	Annual operating costs (£k, 2007 prices)	Total annualised costs (£kpa, 2007 prices)
Coal[1]	80%	72%[3]	147	1,593,573	138,362	133,597	271,960
Gas[2]	80%	100%	42	2,598,164	225,586	133,597	294,407
Total			**189**	**4,191,737**	**363,948**	**267,195**	**566,366**
Coal	80%	36%[4]	74	796,787	69,181	66,799	135,980
Gas	80%	50%	21	1,299,082	112,793	34,411	147,203
Total			**95**	**2,095,869**	**181,974**	**101,209**	**283,183**
Coal	80%	14%[5]	29	318,715	27,672	26,719	54,392
Gas	80%	20%	8	519,633	45,117	13,764	58,881
Total			**38**	**838,347**	**72,790**	**40,484**	**113,273**

[1] Opted in coal fired power stations cover 72% of UK coal fired power stations in terms of waste gas flow rate volumes. The 3 scenarios for opted in coal fired power stations have assumed different SCR uptakes for the opted in coal fired power stations, namely 100%, 50% and 20% SCR uptakes. The opted in coal fired power stations account for about 184 kt of NOx emissions for 2010.

[2] For the purposes of this study it is assumed that 100% uptake of SCR is feasible for all gas fired power stations. Gas fired power stations account for about 53 kt of NOx emissions for 2010.

[3] 100% uptake of SCR from all coal power plants that opt in.

[4] 50% uptake of SCR from all coal power plants that opt in.

[5] 20% uptake of SCR from all coal power plants that opt in.

[6] Lifetime of measure assumed to be 15 years

Using the JEP (2001) cost data gives a cost effectiveness of approximately (2007 prices):

- £1,850 per tonne of NOx reduced for coal fired power stations,
- £7,000 per tonne of NOx reduced for gas fired power stations.

Costs based on other sources of cost data

A different data source, the BREF LCP (2006) document, presents SCR cost data for coal fired power stations in relation to waste gas flow rates (see Table A1.4); these data have been applied to estimate costs for fitting SCR to the power sector using the same scenarios applied above on the JEP (2001) cost data. The methodology and summarised SCR costs are described in the subsections below.

Table A1.4 Information on SCR (BREF, 2006)

Lifetime (years)	Abatement efficiency (%)	Capital costs (million Euros)	Operating costs (million Euros/year) for different flue gas volumes (Nm^3 per hour) [2]					
			200,000 Nm^3/h		500,000 Nm^3/h		1,000,000Nm^3/h	
			Low cost	High cost	Low cost	High cost	Low cost	High cost
15	80% [3]	Use equation "Investment cost = [(x million m3 flue gas volume/1 million m3)^0.7] * EUR 15 million"	0.25	0.29	0.60	0.69	1.17	1.34

[1] Cost prices are for year 2006.

[2] Operating costs for the different flue gas volumes are for raw gas concentrations of 500 mg/Nm3 which are assumed to be reduced to 100 mg/Nm3 i.e. 80% emission reduction. The operating costs include electricity energy, catalysts and reducing agents replacement, maintenance and wear and tear costs.

[3] The BREF LCP document (EC, 2006) indicates that abatement efficiency of 90% or more can be achieved with SCR. However the GAINS model assumes an abatement efficiency of 80% and this is taken into consideration for the analysis.

As capital and operating costs are presented in terms of flue gas volumes per hour (Nm^3/hour) in the BREF LCP document, it was important to estimate the waste gas flow rates per hour. The 2010 fuel activity data provided from AEA was used to calculate the total waste gas flow rates and the load factors calculated previously from the JEP (2001) report analysis were used to calculate waste gas flow rates per hour.

For the capital costs from the BREF LCP (2006) document, the following equation was used to estimate the costs for a flue gas volume (units Nm^3/hour):

"Investment cost = [(x million m^3 flue gas volume at plant/1 million m3)$^{0.7}$] * EUR 15 million"

For operating costs, low and high values have been presented for different flue gas volumes; these are presented in Figure A1.1, where a linear relationship is apparent. These equations for high ($y = 1.3112x + 30306$) and low costs ($y = 1.149x + 22245$) were considered for the cost calculations; the average of these two values was taken to estimate the operating costs.

Figure A1.1 High and low operating costs for SCR (EC LCP BREF, 2006)

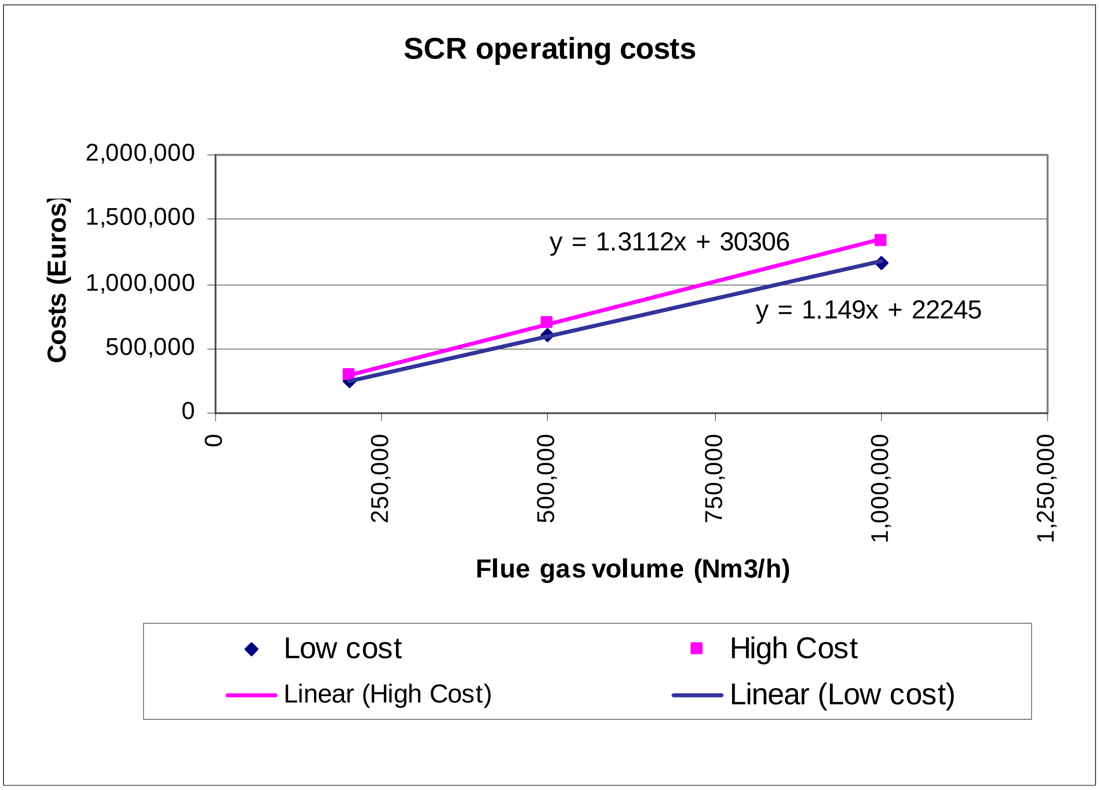

Table A1.5 below summarises the 2010 NOx emission reductions and associated costs for the electricity supply industry for opted in coal fired power stations using the BREF LCP (2006) SCR cost data.

Table A1.5 Summary of SCR measures and costs for the electricity supply industry for (using BREF LCP (2006) cost data)[5]

Measure - SCR[6]	Emission reduction efficiency (%) of measure	Future uptake of measure % (for 2010) [2]	Reduction in 2010 emissions (kt)	Capital Costs (£k, 2007 prices)	Annualised Capital Costs (£k)	Annual operating costs (£k, 2007 prices)	Total annualised costs (£kpa, 2007 prices)
Coal[1]	80%	72%[2]	147	451,371	39,190	66,451	105,641
Coal	80%	36%[3]	74	225,685	19,595	33,225	52,820
Coal	80%	14%[4]	29	90,274	7,838	13,290	21,128

[1] Opted in coal fired power stations cover 72% of UK coal fired power stations in terms of waste gas flow rates volumes. The 3 scenarios for opted in coal fired power stations have assumed different SCR uptakes for the opted in coal fired power stations, namely 100%, 50% and 20% SCR uptakes. The opted in coal fired power stations account for about 184 kt of NOx emissions for 2010.

[2] 100% uptake of SCR from all coal power plants that opt in.

[3] 50% uptake of SCR from all coal power plants that opt in.

[4] 20% uptake of SCR from all coal power plants that opt in.

[5] Lifetime of measure assumed to be 15 years.

Using the BREF LCP (2006) SCR cost data gives a cost effectiveness of approximately £720 per tonne of NOx reduced for coal fired power stations.

The BREF LCP (2006) document further quotes that for an 800MW coal power plant using an SCR unit to reduce NOx emissions, the overall (capital and operating) costs range between 1500 - 2500 Euros per tonne of NOx reduced (approximately £1100 to £1800 per tonne). It is assumed that the underlying data behind the BREF estimates dates from at least six years ago, given the dates of most of the key references in this document.

Data currently available from EGTEI on the costs of retrofitted SCR to coal power plants is based on cost data (from about 2000) for 2 French power stations. The cost functions developed by EGTEI[33] on the basis of this underlying data give a cost of about €2000/t[34] (or approx. £1400/t).

More recent data than the above is data from AEP[35]. They have provided capital cost estimates from various power plants (mainly in the US), which range from £27 – 225 / kWe, with an

[33] http://www.citepa.org/forums/egtei/Costs%20for%20NOx%20abatement%20techniques.xls

[34] Assuming; 1GWe coal plant; 36% electrical efficiency; running at ~40% load factor (3500hrs/year); 15 year SCR equipment lifetime; 260t NOx/PJ emission factor.

[35] Personal Communication with AEP (Association of Electricity Producers), 16th April 2008.

indicative best estimate figure of £125/ kWe.[36] Operating costs comprise a fixed cost of £0.9/kW/yr and a variable cost of £0.62/MWh. All figures are assumed to be in 2007 prices. Using these figures, an estimate of cost effectiveness is approximately £2,050 per tonne of NOx reduced for coal fired power stations (on the same basis of the above estimate based on JEP(2001) data), which represents an approximate 10% to 15% increase in cost compared to estimates based on JEP (2001) data.

AEP highlighted that capital costs are thought to be higher than previously reported mainly due to increased steel prices. Significant amounts of steel are needed for extra ducting. Also it is thought that suppliers may add some premium, given the strong level of demand worldwide for their products, in particular new power stations.

Overall, there is quite a variation in cost data, which is due to influence of site specific factors, variations in materials prices etc. The JEP (2001) data appears to be reasonable as a baseline estimate, within a range of at least +/- 30%.

It should be noted that these costs do not include the costs of any additional outage, which could range from 1 to 3 extra months beyond the usual outage period according to AEP. However, there is significant uncertainty over the length of any additional outage period for an individual installation, and it may be possible that no additional outage period is required.

More detailed research including discussions with plant operators and manufacturers of SCR equipment would be required to determine the costs of SCR in more detail.

A.1.3.3 Summary of Measures and Costs

summarises the 2010 NOx emission reductions and associated costs for the electricity supply industry for opted in coal fired and all the gas fired power stations. The costs in the summary table are based on the JEP 2001 cost data. The range of different estimated costs were summarised in section A.1.3.2.

[36] All the costs presented by AEP are for "high dust" SCR arrangement – for "low dust" SCR the capital costs maybe lower, although there would be a need to reheat the waste gas prior to the SCR which would increase operating costs and CO2 emissions. Note that capital costs exclude any potential costs associated with additional outages during installation of the SCR. AEP estimate additional outage time could be 1 to 3 months.

Table A1.6 Summary of NOx 2010 beyond business as usual abatement measures for opted in coal fired and gas fired power plants (using JEP 2001 cost data)[6]

Measure - SCR	Emission reduction efficiency (%) of measure	Future uptake of measure % (for 2010) [3]	Reduction in 2010 emissions (kt)	Capital Costs (£k, 2007 prices)	Annualised Capital Costs (£k)	Annual operating costs (£k, 2007 prices)	Total annualised costs (£kpa, 2007 prices)
Coal[1]	80%	72%[3]	147	1,593,573	138,362	133,597	271,960
Gas[2]	80%	100%	42	2,598,164	225,586	133,597	294,407
Total			**189**	**4,191,737**	**363,948**	**267,195**	**566,366**
Coal	80%	36%4	74	796,787	69,181	66,799	135,980
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Total			**95**	**2,095,869**	**181,974**	**101,209**	**283,183**
Coal	80%	14%[5]	29	318,715	27,672	26,719	54,392
Gas	80%	20%	8	519,633	45,117	13,764	58,881
Total			**38**	**838,347**	**72,790**	**40,484**	**113,273**

[1] Opted in coal fired power stations cover 72% of UK coal fired power stations in terms of waste gas flow rate volumes. The 3 scenarios for opted in coal fired power stations have assumed different SCR uptakes for the opted in coal fired power stations, namely 100%, 50% and 20% SCR uptakes. The opted in coal fired power stations account for about 184 kt of NOx emissions for 2010.

[2] For the purposes of this study it is assumed that 100% uptake of SCR is feasible for all gas fired power stations. Gas fired power stations account for about 53 kt of NOx emissions for 2010.

[3] 100% uptake of SCR from all coal power plants that opt in.

[4] 50% uptake of SCR from all coal power plants that opt in.

[5] 20% uptake of SCR from all coal power plants that opt in.

[6] Lifetime of measure assumed to be 15 years

A.1.4 References

AEA (2007) “Projected UK emissions of air pollutants. The results and assumptions of the 2005 air quality pollutant emission projections – Draft”

BERR (2007) “Digest of United Kingdom Energy Statistics”

DTI (2007) “Meeting the Energy Challenge. A White Paper on Energy”.

Entec (2007) “Phase I of the NECD Impact Assessment"

European Commission (2006) “Reference Document on Best Available Techniques for Large Combustion Plants”

JEP (2001) “Assessment of England and Wales electricity sector BATNEEC for NOx”

A.2. Offshore oil and gas

A.2.1 Sector Profile

Table A2.1 presents the 2010 NOx emissions for the offshore oil and gas sector developed by AEA[37], based on the BERR UEP 30 forecasts (DTI, 2007) and the 2005 National Atmospheric Emission Inventory (NAEI). The emissions presented are only related to combustion processes.

Table A2.1 2010 NOx emissions for offshore oil and gas

SnapID	Source Name	Activity Name	Projection Year	Emission (kt)
105	Offshore oil and gas - own gas combustion	Natural gas	2010	53.95

In the BREF LCP (EU Commission, 2006) it is mentioned that between the UK and Norwegian offshore sector there are about 270 gas turbines that are covered by the IPPC requirements i.e. the rated thermal input exceeds 50MW. The turbines operated offshore by UK and Norway are mainly of two types:

- "dual fuel" – fuelled either by natural gas from the producing field or by diesel fuel and they cover about 44% of the turbines in the UK and Norway offshore sector (EU Commission, 2006). They are usually employed to generate the electrical power required for the activities performed on the platform and ;
- "single fuel" – fuelled by natural gas and cover the remaining 56% of the UK and Norway offshore sector. They are primarily used for mechanical drives, such as gas compression.

A.2.2 Business as Usual Policies and Abatement Techniques

The IPPC Directive applies to existing installations from October 2007 but it is yet unclear whether any additional NOx abatement techniques are required under BAU policies. The LCP BREF document (2006) presents a number of Best Available Techniques (BAT) that can be applied to reduce NOx emissions from offshore installations, including dry low NOx emissions technique (see below). As it is not clear what is the current performance of existing offshore installations in relation to BAU IPPC commitments, it was assumed that the current BAU commitments would not require further abatement of NOx emissions.

[37] Personal Communication with AEA Energy & Environment, 12th November 2007

A.2.3 Beyond Business as Usual

The BREF LCP document (EU Commission, 2006) presents dry low NOx emissions (DLE) abatement as one of the Best Available Technique (BAT) measures for offshore gas turbines. This has been considered as a Beyond BAU measure for NOx emission reductions.

A.2.3.1 Abatement Techniques

Dry Low NOx emissions (DLE) abatement technology essentially separates the mixing air and fuel and the combustion parts into two successive steps. By mixing combustion air and fuel before combustion, a homogenous temperature distribution and a lower flame temperature are achieved, hence resulting in lower NOx emissions.

DLE abatement technique is applicable to new gas turbines but for retrofitting existing gas turbines there are two technical limitations (EU Commission, 2006):

- Fuel systems – DLE technique for "dual fuel" turbines is not considered mature yet;
- Age of equipment – retrofitting requires a significant upgrade of the controls as well, hence additional space is possibly required which might not be available.

A.2.3.2 Methodology/Assumptions

The BREF LCP document (EU Commission, 2006) presents details for the DLE abatement technique that have been applied for the analysis (see Table A2.2). The abatement efficiency of 86% is based on data from the BREF document that presents unabated NOx emissions from a normal gas turbine to be about 360 mg/Nm3 and NOx emissions with DLE technology to be around 50 mg/Nm^3.

Table A2.2 Information on DLE abatement technique (EU Commission, 2006) [1]

Lifetime (years)	Abatement efficiency (%)	Low cost (Euro/kg NOx reduced)	High cost (Euro/kg NOx reduced)	Average cost (Euro/kg NOx reduced)
15	86%	3	125	64[2]

[1] Costs prices are for year 2006

[2] A range of costs is presented, 3 – 125 Euros/kg NOx reduced, and an average value has been considered for the analysis. The significant range is likely to be due to significant uncertainties regarding costs of retrofitting due to space constraints, possibilities of production interruption etc.

A.2.3.3 Summary of Measures and Costs

Table A2.3 presents the costs of applying DLE technology across the offshore sector. Taking into consideration the technical limitations of applying DLE at offshore gas turbines (especially for "dual fuel" turbines where applicability is still not very mature) and the limited timescales until 2010, a 20% uptake of this technique is considered more realistic and feasible. Further research would be required to understand the profile of the different types of gas turbines i.e. “dual fuel” or “single fuel”, and the spread between existing and new ones.

Table A2.3 Summary of NOx 2010 beyond business as usual abatement measures for offshore oil and gas sector[1]

Measure	Emission reduction efficiency (%) of measure	Future uptake of measure % (for 2010)	Reduction in 2010 emissions (kt)	Capital Costs[3] (£k, 2007 prices)	Annualised Capital Costs (£k)[3]	Annual operating costs (£k, 2007 prices)	Total annualised costs (£kpa, 2007 prices)[2]
DLE - Natural gas	86%	20%	9	-	-	-	425,183

[1] Lifetime of measure assumed to be 15 years

[2] The total annualized costs presented have applied the average cost of 64 Euros/kg NOx reduced, as shown in Table A2.2

[3] Capital and operating costs are not presented since the costs in BREF LCP document are in Euros/kg NOx reduced.

A.2.4 References

DTI (2007) “Meeting the Energy Challenge. A White Paper on Energy”.

European Commission (2006) “Reference Document on Best Available Techniques for Large Combustion Plants”.

A.3. Petroleum Refineries

A.3.1 Sector Profile

Table A3.1 presents the 2010 NOx emissions for Petroleum Refineries developed by AEA[38], based on the BERR UEP 30 forecasts (DTI, 2007) and the 2005 National Atmospheric Emission Inventory (NAEI) [39].

Table A3.1 2010 NOx emissions for petroleum refineries

SnapID	Source Name	Activity Name	Projection Year	Emissions (kt)
103	Refineries	OPG	2010	14.70
103	Refineries	Petroleum coke	2010	11.66
103	Refineries	Fuel oil	2010	3.58
103	Refineries	Natural gas	2010	0.98
103	Refineries	LPG	2010	0.29
103	Refineries	Gas oil	2010	0.26
103	Refineries	Naphtha	2010	0.01

A.3.2 Business as Usual Policies and Abatement Techniques

All petroleum refineries in the UK are opted in under the LCPD requirements. Under BAU policies the petroleum sector is required to meet permit conditions at an installation level under IPPC commitments and is also under the LCP Directive which sets emission limit values for NOx levels for solid, liquid and gaseous fuels. The AEA data provided for petroleum refineries for 2010 NOx emissions have indicated that the refinery bubble under the NERP LCPD requirements is not exceeded using the 2005 emission factors, and hence it has been assumed that this sector will meet its BAU commitments but no further additional measures will be undertaken.

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38 Personal Communication with AEA Energy & Environment, 12th November 2007

39 Projections for 2010 have recently been updated so that 2010 NOx emissions from petroleum refineries are now estimated to be 2kt less than what is presented in this study. Personal Communication with AEA Energy & Environment, 15th May 2008

A.3.3 Beyond Business as Usual

A.3.3.1 Abatement Techniques

Selective catalytic reduction (SCR) has been assumed as a beyond BAU abatement measure that could be installed to further reduce NOx emissions. The BREF document on Petroleum Refineries (EC, 2003) states that SCR is applicable to fluidised bed catalytic crackers (FCC), heaters and boilers or gas turbines. However, the application of SCR to existing installations may be limited by problems of space, pressure and temperature.

A.3.3.2 Methodology/Assumptions

Investment costs of new SCR systems depend largely on the flue gas volume, its sulphur and dust content and the retrofit complexity (e.g. space restrictions and compromises to be taken with existing processes and structures). The BREF document on Petroleum Refineries (EC, 2003) presents various capital and operating costs for SCR. Estimates on the cost-effectiveness of retrofitting SCR are summarised in Table A3.2.

Table A3.2 Cost effectiveness of retrofitting SCR (EC, 2003) [1]

Application of SCR	Cost effectiveness (Euro / tonne NOx removed)[1]
Fired heaters and boilers firing refinery blend gas	8,300 – 9,800
	12,000
	4,200 – 9,000
Boilers firing residual fuel oil	5,000 – 8,000
	4,500 – 10,200
Gas Turbines firing natural or refinery blend gas	1,700 – 8,000
FCCUs	2,800 – 3,300

[1] Includes capital charge of 15%

The capital and operating costs presented in terms of waste gas flow rates as shown in Table A3.3 have been used for this analysis.[40]

[40] A technology provider has confirmed these cost assumptions, if the costs are assumed to be an average.

Table A3.3 Information on SCR abatement technique (EC 2003) [1]

Abatement efficiency (%)	Lifetime (years)	Flue gas flows (Nm3/hour)	Flue gas flows (Nm3/year)	Capital costs (million Euros)			Operation costs (MEuros/y)
				Low	High	Average	
85%	15	360,490	3,000,000,000[2]	15	20	17.5	2

[1] Cost prices are for year 2003

[2] The BREF Petroleum Refinery presents costs for flue gas flows per year. Considering a load factor of 95% (as assumed in the EU ETS Phase II New Entrants spreadsheets for BERR[41]), a flue gas flow per hour is calculated.

In order to calculate the waste gas flow rates for the different fuels the following assumptions were taken:

- for petroleum coke (AEA activity data for 2010 are given in terms of million tonnes consumed) a gross calorific value of 35.8 GJ/tonne (BERR, 2007) is applied for coke and a default coal specific volume of 370 Nm^3/GJ is assumed;
- for OPG (AEA activity data for 2010 are given in million therms) a default gas specific volume factor of 283 Nm^3/GJ is used;
- for fuel oil (AEA activity data did not provide any fuel activity input for 2010 for this fuel) the latest UK NERP tables for LCPD[42] were used to find the fuel oil consumption (in GJ)[43] and a default fuel oil specific volume factor of 300 Nm^3/GJ is used.

Based on Table A3.3 a cost-effectiveness of approximately £2,581/t NOx reduced has been estimated for this study. This is within the range presented in the BREF (Table A3.2), once converted to £/t.

A.3.3.3 Summary of Measures and Costs

Table A3.4 presents the costs of applying SCR technology across petroleum refineries (for OPG, petroleum coke and fuel oil) for different uptakes. Taking into consideration the limited timescales until 2010 and the fact that the NERP LCP bubble is not exceeded in 2010 (and hence refineries will not install any further abatement technology as a BAU measure), a low uptake of this abatement techniques is more likely e.g. 20%.

[41] http://www.berr.gov.uk/files/file38383.xls

[42] http://www.environment-agency.gov.uk/commondata/103599/lcpd_final_plan_1934830.doc

[43] Note that the NERP tables present fuel oil consumption for period 1996-2000. This has been assumed to be similar to the fuel oil consumption for 2010

Table A3.4 Summary of NOx 2010 beyond business as usual abatement measures for petroleum refineries[1]

Measure	Emission reduction efficiency (%) of measure	Future uptake of measure % (for 2010)	Reduction in 2010 emissions (kt)	Capital Costs[2] (£k, 2007 prices)	Annualised Capital Costs (£k)	Annual operating costs (£k, 2007 prices)	Total annualised costs (£kpa, 2007 prices)
SCR - All fuels	85%	100%	25.4	326,553	28,353[3]	37,320[3]	65,673
SCR - All fuels	85%	50%	12.7	163,276	14,176	18,660	32,837
SCR - All fuels	85%	20%	5.1	65,311	5,671	7,464	13,135

[1] Lifetime of measure assumed to be 15 years

[2] For capital costs, costs are based on average values

[3] Using various other capital and operating costs presented in terms of waste gas flow rates in the BREF (EC, 2003) (i.e. not the ones shown in Table A3.3), and assuming a 100% uptake, annualised capital costs are thought to be in the range of £6-35M and annual operating costs in the range of £7-39k

A.3.4 References

BERR (2007) "Digest of United Kingdom Energy Statistics (DUKES) – A national statistics publication"

DTI (2007) "Meeting the Energy Challenge. A White Paper on Energy".

European Commission (2003) "Integrated Pollution Prevention and Control (IPPC) - Reference Document on Best Available Techniques for Mineral Oil and Gas Refineries"

A.4. Domestic households

A.4.1 Sector Profile

Table A4.1 presents the 2010 NOx emissions for the residential sector developed by AEA[44], based on the BERR UEP 30 forecasts (DTI, 2007) and the 2005 National Atmospheric Emission Inventory (NAEI). It is clear that the key source of NOx emissions is domestic combustion of natural gas, hence the analysis for the domestic sector for 2010 has focused on these emission sources.

Table A4.1 2010 NOx emissions for the residential sector

SnapID	Source Name	Activity Name	Projection Year	Emission (kt)
202	Domestic combustion	Anthracite	2010	1.02
202	Domestic combustion	Burning oil	2010	7.12
202	Domestic combustion	Coal	2010	0.99
202	Domestic combustion	Coke	2010	0.09
202	Domestic combustion	Fuel oil	2010	0.00
202	Domestic combustion	Gas oil	2010	0.43
202	Domestic combustion	LPG	2010	0.73
202	Domestic combustion	Natural gas	2010	81.30
202	Domestic combustion	Peat	2010	0.16
202	Domestic combustion	Petroleum coke	2010	0.30
202	Domestic combustion	SSF	2010	0.30
202	Domestic combustion	Town gas	2010	0.00
202	Domestic combustion	Wood	2010	0.48

[44] Personal Communication with AEA Energy & Environment, 12th November 2007

A.4.2 Business as Usual Policies and Abatement Techniques

Based on 2001 census data, around 92% of dwellings have central heating installed. A large number of households also have energy efficient measures in place, which reduce energy consumption and therefore NO_x and other emissions. The main measures include:

- Loft installation;
- Cavity wall installation;
- Double glazing;
- Draught proofing;
- Tank/pipe insulation;
- Condensing boilers.

Under the existing 'Energy Efficiency Commitment' (EEC) within the UK's overall Climate Change Programme it is assumed that reductions in NO_x emissions from the domestic sector will occur either through further installation of insulation measures or boiler replacements with more efficient models. Costs for these measures were reported in the revision of cost curve for NOx report (Entec, March 2003).

The Carbon Emissions Reduction Target (CERT) (previously also known as Energy Efficiency Commitment 2008-11 or EEC3) will apply in England, Scotland and Wales. The CERT would build on the success of the EEC as the Government's principal policy mechanism for cost effective delivery of energy saving measures to households.

"The first phase of the EEC (2002-05) stimulated about £600m investment in energy efficiency and delivered net benefits to householders in excess of £3 billion. It is expected to save 0.3 MtC annually by 2010, with overall cost-effectiveness of about £300 per tonne of carbon saved (i.e. net benefits) and costs to suppliers of around £3.20 per customer per fuel per year. Around 10 million households have benefited from EEC 2002-05. EEC 2005-08 resulted in broadly double the level of activity of EEC 2002-05 and is expected to deliver 0.5 MtC annually by 2010" (Defra, 2007).

SEDBUK (Seasonal Efficiency of Domestic Boilers in the UK) was developed under the Government's Energy Efficiency Best Practice Programme with the co-operation of boiler manufacturers, and provides a basis for fair comparison of the energy performance of different boilers.

SEDBUK is the average annual efficiency achieved in typical domestic conditions, making reasonable assumptions about pattern of usage, climate, control, and other influences. It is calculated from the results of standard laboratory tests together with other important factors such as boiler type, ignition arrangement, internal store size, fuel used, and knowledge of the UK climate and typical domestic usage patterns.

Since the 1st April 2005 the boiler provisions in the revised Building Regulations for England and Wales require all boilers to be replaced by boilers with a SEDBUK A or B rating. A-rated boilers being more than 90% efficient whereas a B-rated boilers being between 86-90% efficient.

A.4.3 Beyond Business as Usual

A.4.3.1 Abatement Techniques

The CEN standard for gas boilers, EN 483, allows five NOx emission classes. Presently Building Regulations do not specify a NOx class. Therefore, the beyond BAU NOx abatement measure for domestic households that has been considered is the replacement of old boilers with boilers that have to meet one of the highest two NOx classes, that is a class 4 or 5.

A.4.3.2 Methodology/Assumptions

It has been assumed that boilers that meet one of the highest two NOx classes, (class 4 or 5) will have a rating of SEBDUK A rather than a rating of A or B.

The size of a boiler required will vary depending on several factors such as the size of the house, number of rooms, number of radiators, level of insulating and so forth. Therefore in order to encompass a wide range of boiler sizes that may be required for a domestic household, boilers of up to 40kW have been considered.

About 7 million boilers are thought to be over 15 years old. Hence, the maximum uptake replacement rate of old boilers was assumed to be around 30% for 2010. The slow take up of condensing boilers is due to the reluctance of consumers to pay more, combined with resistance of installers and the difficulty of installing condensing boilers in certain dwellings.[45]

The natural replacement rate of boilers is estimated to be between 5% (Defra, 2007) and 10% (BRE, 2003) per annum, from which a % could comply with the tighter NOx emission standards. For the first scenario it has been assumed that under BAU 50% of boilers will be replaced with a boiler with a rating of SEDBUK A and 50% of boilers will be replaced with a boiler with a rating of SEDBUK B. Hence over a two year period, the beyond BAU uptake of SEDBUK A boilers has been assumed to be 5%. Under the second scenario the beyond BAU uptake of SEDBUK A boilers has been assumed to be 20% to reflect a higher uptake than the natural boiler replacement rates.

The capital costs of the scenarios is estimated based on the cost differential between an average size new boiler that meets the tighter NOX standards (assumed to be SEDBUK A) and an average size boiler that meets the minimum standards (SEDBUK B). The additional cost of buying a SEDBUK A rated boiler compared to a B rated boiler has been estimated based on the cost of 76 boilers (52 A rated boilers and 24 B rated boilers) from 14 different manufacturers and are shown in Table A4.2. The approach is presented below in Table A4.3:

[45] http://www.energysavingtrust.org.uk/uploads/documents/aboutest/Potential_market_for_micro_CHP_2002.pdf

Table A4.2 Summary costs (£) of SEDBUK A and B Condensing Combi boilers[1]

	Low cost (£)	High cost (£)	Average cost (£)
Cost of SEDBUK A boiler	472	1082	752
Cost of SEDBUK B boiler	380	644	524
Additional cost	92	438	228

[1] Based on prices on-line (http://www.heatandplumb.com/ - accessed in Nov 2007)..

Table A4.3 Cost scenarios for measure 1 – Replacement boilers are SEDBUK A rated only

	Low cost	High cost	Average cost
Number of households in the UK[1]	22,456,465	22,456,465	22,456,465
Additional cost of SEDBUK A boiler (£)	£92	£438	£228
Boiler replacement rate[2]	5%	5%	5%
Maximum uptake of condensing boilers[2]	95%	95%	95%
Total capital cost (£m)[3]	£98m	£467m	£243m
Annualised cost (£m)[4]	£6.9m	£32.8m	£17.1m
	Low cost	**High cost**	**Average cost**
Number of households in the UK[1]	22,456,465	22,456,465	22,456,465
Additional cost of SEDBUK A boiler (£)	£92	£438	£228
Boiler replacement rate[2]	20%	20%	20%
Maximum uptake of condensing boilers[2]	95%	95%	95%
Total capital cost (£m)[3]	£393m	£1,867m	£972m
Annualised cost (£m)[4]	£27.6m	£131.4m	£68.4m

[1] Only the number of households with residents and with central heating have been used based on 2001 census data

[2] DTI (2003). The maximum uptake is limited to 95% due to constraints with drainage

[3] This assumes that the boilers are replaced at their natural rate, and hence no installation costs are applicable as they would have been incurred if a SEDBUK B boiler was installed instead

[4] Using a 20 year lifetime period in accordance with the press release by DTI (2003)

A.4.3.3 Summary of Measures and Costs

Table A4.4 summarises the estimated additional cost of purchasing a condensing boiler with a rating of SEBDUK A, rather than a rating of SEBDUK B. The costs in the summary table are based on the average cost of a SEBDUK A rated boiler. The range of costs were summarised in Table A4.3.

Table A4.4 Summary of NOx 2010 beyond business as usual abatement measures for domestic households[1]

Measure	Emission reduction efficiency (%) of measure	Future uptake of measure % (for 2010)	Reduction in 2010 emissions (kt)	Capital Costs (£k, 2007 prices)	Annualised Capital Costs (£k)	Annual operating costs (£k, 2007 prices)	Total annualised costs (£kpa, 2007 prices)
SEDBUK A gas boilers	67%	5%	2.7	243,001	17,098	0[2]	17,098
SEDBUK A gas boilers	67%	20%	10.9	972,002	68,391	0[2]	68,391

[1] Lifetime of measure assumed to be 20 years

[2] Energy efficiency savings are expected from this measure. The scale of energy efficiency gains, over and above SEDBUK B rated boilers, are currently not clear based on existing data available. Hence these gains have not been quantified and the additional operating costs are assumed to be zero. The approach adopted here, of just using the difference in capital costs, is therefore likely to overestimate the costs. This approach is consistent with the economic analysis to inform the AQSR (Defra, July 2007).

A.4.4 References

BRE (2003), Domestic energy fact file 2003, L D Shorrock and J I Utley, BRE Housing Centre

Defra (2007), Carbon Emissions Reduction Target April 2008 to March 2011, Consultation Proposals http://www.defra.gov.uk/corporate/consult/cert2008-11/consultation.pdf

Defra (July 2007), Economic Analysis to inform the Air Quality Strategy, http://www.defra.gov.uk/environment/airquality/publications/stratreview%2Danalysis/

DTI (2003), Department of Trade and Industry Statistical Press Release P2003/236

Entec (March 2003), Revision of cost curve for NOx. A report for Defra.

Entec (May 2005), Standardisation of the cost estimates of policies in the Air Quality Strategy Review. A report for Defra.

A.5. Iron and Steel Works

A.5.1 Sector Profile

Table A5.2 presents the 2010 NOx emissions Iron and Steel developed by AEA[46], based on the BERR UEP 30 forecasts (DTI, 2007)) and the 2005 National Atmospheric Emission Inventory (NAEI). The emissions presented are only related to combustion processes.

Table A5.1 2010 NOx emissions for iron and steel

SnapID	Source Name	Activity Name	Projection Year	Emissions (kt)
301	Iron and steel - combustion plant	Blast furnace gas	2010	3.22
301	Iron and steel - combustion plant	Coke	2010	0.02
301	Iron and steel - combustion plant	Coke oven gas	2010	0.99
301	Iron and steel - combustion plant	Fuel oil	2010	1.45
301	Iron and steel - combustion plant	Gas oil	2010	0.00
301	Iron and steel - combustion plant	Natural gas	2010	8.08
301	Iron and steel - combustion plant	Town gas	2010	0.00

A.5.2 Business as Usual Policies and Abatement Techniques

For iron and steel works, it is assumed that low NO_x burners are being fitted as a BAU measure, as part of improvement programmes under IPPC. Although the iron and steel sector involves a wide range of complicated processes, the NO_x mass emissions are relatively small in comparison to other sources considered in this study, therefore this has not been a priority sector for investigation.

[46] Personal Communication with AEA Energy & Environment, 12th November 2007

A.5.3 Beyond Business as Usual

A.5.3.1 Abatement Techniques

Selective catalytic reduction is considered beyond BAU and has been considered for the Iron and Steel sector.

A.5.3.2 Methodology/Assumptions

The unit cost of SCR has been estimated using data from the GAINS models (using scenario NEC_NAT_CLEV4). It should be noted that the unit costs presented for gas have been applied for all fuel types. The results are summarised below:

Table A5.2 Cost data developed from the GAINS model

Technique	GAINS reference number	Unit Cost Euro/t NOx[1] (2002 prices)	Annualised unit cost/t (£) (2007 prices)	Potential on top of CLE[2] (%)	Application limit (%)
Combustion Modification	A/1-GAS-IN_BO-IOGCM	808	601	87	100
Combustion Modification & SCR	B/1-GAS-IN_BO-IOGCSC	3,640	2,709	80	80
Estimated SCR cost	N/A		6,223		

[1] All costs quoted in GAINS are in Euro 2000 prices (http://www.iiasa.ac.at/web-apps/apd/gains/cost.EU/index.menu).

[2] CLE refers to current legislation

A.5.3.3 Summary of Measures and Costs

Table A5.3 summarises the estimated cost of SCR for this sector.

Table A5.3 Summary of NOx 2010 beyond business as usual abatement measures for the Iron and Steel sector[1]

Measure	Emission reduction efficiency (%) of measure	Future uptake of measure % (for 2010)	Reduction in 2010 emissions (kt)	Capital Costs (£k, 2007 prices)	Annualised Capital Costs (£k)	Annual operating costs (£k, 2007 prices)	Total annualised costs (£kpa, 2007 prices)
SCR – all fuels	80%	20%	2.2	-	-	-	13,690

[1] Lifetime of measure assumed to be 15 years

A.5.4 References

Entec (March 2003), Revision of cost curve for NOx. A report for Defra.

GAINS Model, Scenario NEC_NAT_CLEV4, http://www.iiasa.ac.at/web-apps/apd/gains/cost.EU/index.menu.

A.6. Cement Clinker production

A.6.1 Sector Profile

Table A6.1 presents the 2010 NOx emissions for cement clinker production developed by AEA[47], based on the BERR UEP 30 forecasts (DTI, 2007)) and the 2005 National Atmospheric Emission Inventory (NAEI).

Table A6.1 2010 NOx emissions for cement clinker production

SnapID	Source Name	Activity Name	Projection Year	Emissions (kt)
30311	Cement - non-decarbonising	Clinker production	2010	22.57

A.6.2 Business as Usual Policies and Abatement Techniques

IPPC

The main BAU policy which has affected cement manufacturing processes has been IPPC. Under this system, the main NO_x control measures used have been kiln operational techniques. Modern kilns have complex computer systems which monitor and control the kiln to keep conditions stable and control the burn, which are efficient at controlling NO_x emissions. It has been assumed that these systems are in place at all kilns in the sector and therefore this technique is assumed to be BAU.

There are currently 15 cement plants in the UK (BCA, July 2007) of which 6 plants already have SNCR (EC, 2007).

Alternative fuels

With fuel representing some 35% of variable costs, the need to remain competitive has led the industry to examine several alternative fuels over the past ten years. These have included used tyres, recycled liquid fuels, plastic packaging wastes, animal products (tallow and meat and bone meal) and sewage sludge pellets. As a result of its development work, the industry now has a significant role to play in developing solutions for the country's problems in dealing with hazardous and other wastes. By extracting energy from these wastes, it effectively lifts them up what is known as the "waste hierarchy", and significantly reduces the volumes going to landfill. Currently the industry burns about 50% of the used solvents available in the UK; 10%of

[47] Personal Communication with AEA Energy & Environment, 12th November 2007

available packaging waste and has the capacity to handle about 50%of the total volume of waste tyre arisings (BCA 2007). The reduction in NO_x emissions achieved by substituting alternative for traditional fuels varies depending on the fuel type, substitution rate and kiln characteristics.

WID

The use of alternative fuels means that kilns will be required to meet the limits in the WID. This contains a NO_x limit of 800mg/m^3 by 2005 for cement kilns burning waste fuels, with derogation to 2008 for wet kilns or those using under 3 tonnes of waste fuel per hour, providing the emissions do not exceed 1200mg/m^3.

A.6.3 Beyond Business as Usual

A.6.3.1Abatement Techniques

Two NOx abatement techniques considered beyond BAU (at least for some sites) have been considered for the cement sector:

- Selective non-catalyst reduction (SNCR);
- Selective catalytic reduction (SCR).

SNCR can achieve NOx reductions in the region of 200mg/m3 to 800mg/m3 (EC, 2007). It is assumed that plants in the UK installing state of the art SNCR could achieve 200mg/m3, i.e. a 60% reduction in mass emissions (Entec 2003). The maximum potential further uptake of this measure has been assumed to be 60% as currently there are currently 15 cement plants in the UK (BCA, July 2007) of which 6 plants already have SNCR (EC, 2007).

SCR reduces NO and NO_2 to N_2 with the help of NH_3 and a catalyst at a temperature range of about 300-400^{o}C. This technology is widely used for NO_x abatement in other industries (coal-fired power stations, waste incinerators). In the cement industry, two systems are considered: low dust configuration between a dedusting unit and stack, and a high dust configuration between a preheater and a dedusting unit. Low dust exhaust gas systems require the reheating of the exhaust gases after dedusting, which may cause additional energy cost and pressure losses. High dust systems are considered preferable for technical and economical reasons. These systems do not require reheating, because the waste gas temperature at the outlet of the preheater system is usually in the right temperature range for SCR operation (EC, 2007).

Large NO_x emission reductions of 85-95% are potentially achievable by SCR high dust systems and until now, only high dust systems have been tested in the cement sector. The draft 2007 BREF refers quotes reduction efficiency in the range of 60-95%. However there is unlikely to be any uptake of SCR in the UK under BAU policies given that the capital costs of installing SNCR are much cheaper.

An additional technique is flame cooling, which involves the addition of water to the fuel or directly to the flame by using different injection methods, such as injection of one fluid or two liquids (liquid and compressed air or solids) or the use of liquid/soil wastes with a high water content reduces the temperature and increase concentration of hydroxyl radicals. This can have a positive effect on NOx reduction in the burning zone. Reduction efficiencies from 10-35%

have been reported (EC, 2007). However, this technology has not been considered as a beyond BAU measure, as its effectiveness is not as good as SNCR.

A.6.3.2 Methodology/Assumptions

The costs used in the database are based on the IPPC cement and lime BREF document (EC, 2007). The BREF document contains several examples of plants that have installed these technologies. These examples have been used to determine a range of costs (low, high and average) relevant to the total UK clinker capacity of 12.29 million tonnes per year[48]. It should be noted that this approach is limited by the use of past clinker capacity and not projected capacity in 2010. The results are summarised below in Table A6.2:

Table A6.2 Summary of the costs (2007 prices) of each measure (£M) for the cement sector[1]

	Low cost	High cost	Average cost
SNCR			
Capital cost	5.0	12.0	8.1
Annualised capital cost	0.4	1.0	0.7
Operating cost	2.8	5.4	4.0
SCR			
Capital cost	34.8	89.5	56.7
Annualised capital cost	3.0	7.8	4.9
Operating cost	12.2	18.7	15.7

[1] It has been assumed that if a plant has or is planning to fit SNCR, SCR would not be considered as an additional measure.

A.6.3.3 Summary of Measures and Costs

Table A6.3 summarises the estimated cost of each NOx abatement technology for the cement sector. The costs in the summary table are based on the average cost of each abatement technology. The range of costs were summarised in Table A6.2.

[48] http://www.mineralsuk.com/britmin/mp5_cement_latest.pdf

Table A6.3 Summary of NOx 2010 beyond business as usual abatement measures for the cement sector

Measure	Emission reduction efficiency (%) of measure	Future uptake of measure % (for 2010)	Reduction in 2010 emissions (kt)	Capital Costs (£k, 2007 prices)	Annualised Capital Costs (£k)	Annual operating costs (£k, 2007 prices)	Total annualised costs (£kpa, 2007 prices)
SNCR	60%	20%	2.7	1,625	141	792	933
SCR	80%	10%	1.8	5,669	492	1,575	2,067

A.6.4 References

BCA (2007), British Cement Association, industry sector profile: http://www.cementindustry.co.uk/the_industry/profile.aspx

BCA, (July 2007), British Cement Association, Cement prices and supplies – the facts: http://www.cementindustry.co.uk/pdf/Cement%20supplies%20and%20prices%20-%20100707.pdf

EC (2007), European Commission, 2007. Integrated Pollution Prevention and Control (IPPC) Reference Document on Best Available Techniques in the Cement and Lime Manufacturing Industries, Draft September 2007.

Entec (March 2003), Revision of cost curve for NOx. A report for Defra.

Entec (2006), EU Emissions Trading Scheme Phase II Review of New Entrants' Benchmarks-Cement. Report version two for DTI.

A.7. Other industrial combustion

A.7.1 Sector Profile

Table A7.1 presents the 2010 NOx emissions industrial combustion and autogenerators developed by AEA[49], based on the BERR UEP 30 forecasts (DTI, 2007) and the 2005 National Atmospheric Emission Inventory (NAEI). It is clear that the key source of NOx emissions is natural gas, hence the analysis for this sector for 2010 has focused on these emission sources. However, according to the NAEI coal is also an important source of NOx emissions and abatement measures for this may need to be considered in future work.

Table A7.1 2010 NOx emissions for other industrial combustion and autogenerators

SnapID	Source Name	Activity Name	Projection Year	Emissions (kt)
301	Other industrial combustion	Burning oil	2010	4.93
301	Other industrial combustion	Coal	2010	3.26
301	Other industrial combustion	Coke	2010	7.74
301	Other industrial combustion	Coke oven gas	2010	0.07
301	Other industrial combustion	Colliery methane	2010	0.01
301	Other industrial combustion	Fuel oil	2010	4.96
301	Other industrial combustion	Gas oil	2010	12.87
301	Other industrial combustion	LPG	2010	3.24
301	Other industrial combustion	Lubricants	2010	1.04
301	Other industrial combustion	Natural gas	2010	50.53
301	Other industrial combustion	OPG	2010	0.41
301	Other industrial combustion	Petroleum coke	2010	0.00
301	Other industrial combustion	Town gas	2010	0.00
301	Other industrial combustion	Wood	2010	0.51
301	Autogenerators	Coal	2010	7.57
301	Autogenerators	Natural gas	2010	15.88

Other industrial combustion is thought to include combustion in industries such as chemicals, rubber and plastics, non-ferrous metals, food and drink, minerals (e.g. bricks, glass and plaster),

49 Personal Communication with AEA Energy & Environment, 12th November 2007

textiles, electrical and mechanical engineering, paper, printing and publishing, and other sources not included elsewhere.[50] Autogeneration is generation of electricity by companies whose main business is not electricity generation, so the electricity is being produced mainly for the company's own use.

A.7.2 Business as Usual Policies and Abatement Techniques

The majority of industrial gas combustion is in boilers rather than turbines. Low NO_x burners are not common, limited mainly to environmentally-focussed companies or areas with specific NO_x problems.

A.7.3 Beyond Business as Usual

A.7.3.1 Abatement Techniques

The two beyond BAU abatement measures that have been considered are combustion modifications (CM); and a combination of combustion modification and selective catalytic reduction (SCR). The combined measure is considered due to uncertainties with regards to the BAU measures in place. Both of these measures are applied to gas combustion only. Combustion modification has not been considered for autogenerators

A.7.3.2 Methodology/Assumptions

The unit cost of each abatement technology has been estimated using data from the GAINS models (using scenario NEC_NAT_CLEV4). The results are summarised below:

Table A7.2 Cost data developed from the GAINS model

Technique	GAINS reference number	Unit Cost Euro/t NOx[1] (2002 prices)	Annualised unit cost/t (£) (2007 prices)	Potential on top of CLE[2] (%)	Application limit (%)
Combustion Modification	A/1-GAS-IN_BO-IOGCM	808	601	87	100
Combustion Modification & SCR	B/1-GAS-IN_BO-IOGCSC	3,640	2,709	80	80

[1] All costs quoted in GAINS are in Euro 2000 prices (http://www.iiasa.ac.at/web-apps/apd/gains/cost.EU/index.menu).

[2] CLE refers to current legislation

[50] Personal Communication with AEA Energy & Environment, 4th December 2007

A.7.3.3 Summary of Measures and Costs

Table A5.3 summarises the estimated cost of each NOx abatement technology for this sector.

Table A7.3 Summary of NOx 2010 beyond business as usual abatement measures for other industrial combustion and autogenerators[1]

Measure	Emission reduction efficiency (%) of measure	Future uptake of measure % (for 2010)	Reduction in 2010 emissions (kt)	Capital Costs (£k, 2007 prices)	Annualised Capital Costs (£k)	Annual operating costs (£k, 2007 prices)	Total annualised costs (£kpa, 2007 prices)
CM - Gas	50%	20%	5.1	-	-	-	3,038
CM & SCR -Gas	80%	10%	5.3	-	-	-	14,397

[1] Lifetime of measure assumed to be 15 years

A.7.4 References

Entec (March 2003), Revision of cost curve for NOx. A report for Defra.

GAINS Model, Scenario NEC_NAT_CLEV4, http://www.iiasa.ac.at/web-apps/apd/gains/cost.EU/index.menu

A.8. Road Transport

A.8.1 Sector Profile

Table A8.1 presents the projected 2010 NO_x emissions for UK road transport developed by AEA[51] based on the BERR UEP 30 forecasts (DTI, 2007) and the 2005 National Atmospheric Emission Inventory (NAEI). The key sources for NO_x within road transport are petrol and diesel cars, diesel LGVs, rigid and articulated HGVs and, to a lesser extent, buses. The possibility of NO_x emission reductions for 2010 does not necessarily focus on the largest sources because reduction potential can be higher, as well as more feasible in terms of implementation, for captive fleets (e.g. HGVs and buses)

Table A8.1 2010 NOx emissions for the road transport sector

SnapID	Source Name	Activity Name	Projection Year	Emissions (kt)
7	Cars	Petrol	2010	84.88 [1]
7	Cars	DERV	2010	63.95 [1]
7	LGV	Petrol	2010	2.09 [1]
7	LGV	DERV	2010	45.33 [1]
7	HGV (rigid)	DERV	2010	55.25 [2]
7	HGV (articulated)	DERV	2010	115.01 [2]
7	Buses	DERV	2010	25.59 [2]
7	Motorcycles	Petrol, 2-stroke	2010	0.02 [2]
7	Motorcycles	Petrol, 4-stroke	2010	1.02 [2]

1 Incorporates the impact of Euro 5 & 6 on LDVs

2 Traffic projections continue to be based on the Central traffic forecasts for GB from DfT (July 2004) by area and vehicle type, from "The Future of Transport - White Paper CM 6234". Diesel car sales are assumed to grow to 42% by 2010

The data on 2010 BAU emissions projections of NOx are further disaggregated by vehicle emission standard from data provided by AEA[52], and are shown in Table A8.2.

[51] Personal Communication with AEA Energy & Environment, 12th November 2007

[52] Personal Communication with AEA Energy & Environment, 4th December 2007

Table A8.2 Disaggregated 2010 NOx emissions for the road transport sector.

Vehicle Type	2010 NOx emissions (kt)						
	Pre-Euro 1	**Euro 1**	**Euro 2**	**Euro 3**	**Euro 4**	**Euro 5**	**Euro 6**
Petrol cars	0.86	7.89	32.14	13.31	29.25	1.43	-
Diesel cars	0.02	0.78	4.38	27.06	28.73	2.98	0.00
Petrol LGV	0.08	0.06	0.52	0.57	0.86	0.00	-
Diesel LGVs	0.32	1.20	9.31	16.49	18.01	0.00	0.00
	Pre-Euro I	**Euro I**	**Euro II**	**Euro III**	**Euro IV**	**Euro V**	**Euro VI**
Rigid HGV	0.00	0.22	13.11	25.51	9.60	6.80	-
Artic HGV	0.00	0.29	14.78	54.93	26.26	18.75	-
Buses	0.79	1.04	6.61	11.16	3.50	2.50	-
Motorcycles 2st	0.01	0.01	0.00	0.00	-	-	-
Motorcycles 4st	0.23	0.41	0.26	0.11	-	-	-

A.8.2 Business as Usual Policies and Abatement Techniques

As noted in Table A8.1, the 2010 NO_x emission projections now incorporate the impact of Euro 5 and 6 standards on light duty vehicles (LDVs) because they have been agreed in legislation, the first of which will be introduced from July 2010. The previous emission projections of UEP26(2004) and UEP26(2005) did not include the impact of this new legislation as it had not been agreed when these projection estimates were developed. It is anticipated that the tighter NO_x standards for Euro 6 diesel cars and light goods vehicles (LGVs) are likely to require catalyst-based technologies such as SCR or lean NO_x traps (LNT); this Euro 6 standard is scheduled for introduction in 2015.

For heavy duty vehicles (HDVs), i.e. heavy goods vehicles (HGVs) and buses and coaches, the Euro V standard is included in BAU projections as it is in legislation, but the Euro VI standard has not yet been agreed (although a consultation on proposed limit values has recently ended), and so is treated as a beyond BAU measure. The consultation included four scenarios for emission limit values.

A.8.3 Beyond Business as Usual

A.8.3.1 Abatement Techniques

Both technical and non-technical abatement measures for the reduction of NOx from road transport have been considered for this 2010 cost curve and include;

- Speed limit enforcement (measure N1.1);

- Transfer of freight from road to rail (measure N2.1);
- Retrofitting SCR to HDVs (measures T1.1 and T1.2);
- Retro-converting HDVs to use CNG (measure T2.1);
- Replacement of existing vehicles with hybrids (measures T3.1 and T3.2);
- Euro VI standard for HDVs (measures T4.1 and T4.2);
- Low emission vehicles (LEVs) (measure T5.1).

Due to time constraints the number of non-technical abatement measures included is limited to two, but it is noted that a number of non-technical abatement measures for road transport exist which have very promising abatement efficiencies, and could be explored further for future NECs in 2020. Such measures include, but are not limited to, eco-driving, road pricing, smarter choices[53], information provision and awareness campaigns and restrictions of vehicle use in high pollution episodes. Although this latter measure may not greatly aid compliance with national emission ceilings, it would improve compliance with local air quality limit values. At the time of writing, data availability on likely abatement efficiencies is limited. Road pricing has been identified in a recent report for the Dutch Government undertaken by Environmental Assessment Agency (MNP)[54] (September 2007) as the most cost-effective national option that could be taken for reducing NOx and PM emissions and ambient air concentrations and official proposals have since been published for the scheme (December 2008). Road pricing was considered in the AQSR for the UK; however only emission reductions were calculated (i.e. no costs were presented). Road pricing could have significant impacts on emissions from road transport depending on the design of the scheme and, in particular, the level at which any charges are set. However, it is extremely unlikely that a road pricing scheme could be in place in the UK in time for 2010 (the AQSR assumed implementation from 2015 onwards at the earliest).

A.8.3.2 Methodology/Assumptions

The vehicle fleet size and composition in 2010 has been estimated by taking into account current road vehicle numbers from the Department for Transport (DfT, 2007) and from stock projections provided by AEA[55]. Table A8.3 details the estimated numbers of vehicles of each type in 2005 and 2010; intervening years are calculated for the purposes of the study using those data and forecasts and assuming a linear interpolation.

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[53] "*Smarter Choices are techniques for influencing people's travel behaviour towards more sustainable options such as encouraging school, workplace and individualised travel planning. They also seek to improve public transport and marketing services such as travel awareness campaigns, setting up websites for car share schemes, supporting car clubs and encouraging teleworking.*" DfT, 2007 (available from: http://www.dft.gov.uk/pgr/sustainable/smarterchoices/)

[54] Available from: http://www.mnp.nl/en/publications/2007/Cost-effectiveness_of_additional_abatement_options_for_cleaner_air.html

[55] Personal Communication with AEA Energy & Environment, 4th December 2007

Table A8.3 Vehicle Fleet Numbers and Composition (000s)

Vehicle Type	2005 (000s)	2010 (000s)
Petrol cars	20,754	18,926
Diesel cars	5,377	8,687
Petrol LGV	267	315
Diesel LGVs	2,752	2,816
Rigid HGV	324	292
Artic HGV	120	127
Buses	103	114
Motorcycles 2st	341	302
Motorcycles 4st	659	859
Total	**30,698**	**32,438**

The data in Table A8.3 above can be further broken down by Euro standard and the number of new vehicles projected to be bought each year can be estimated. However, the available data only allows for estimating the number of new vehicles bought each year in terms of an exchange from an older Euro standard to a newer standard (for example, replacing a Euro II car with a Euro IV car) but not within Euro standards (for example, replacing a Euro III car with a Euro III car). By 2010 the natural fleet turnover is starting to eliminate the older pre-Euro I and Euro I standards, with increasingly large fractions of Euro 4 (LDVs) or Euro V (HDVs).

The technical and non-technical abatement measures considered are described in this section, with details of their assumptions, costs and abatement efficiencies.

Speed limit enforcement (measure N1.1)

This non-technical measure takes into consideration that a large proportion of vehicles on motorways drive above the speed limit and that emissions of NOx (and other exhaust gases) are increased at higher speeds. Thus by lowering the average speed of vehicles on the motorways, emissions are reduced.

DfT provide observation-based statistics on the proportions of vehicles travelling in different speed brackets on motorways (DfT, 2007). From these data, the fraction of cars exceeding the speed limit was found to be 54%, at an average speed of 77.98mph. Although 50% of LGVs were noted to be also exceeding the speed limit, these have not been included in the measure due to time constraints. HDVs are not known for breaking speed limits (Dft, 2007) due to them being electronically limited. The NAEI hold data on speed-dependent emission factors for various pollutants, including NOx from each class of vehicle; data from the 2005 NAEI were provided by AEA [56]. Using the fraction emission reductions indicated by the speed-dependent emission factors applied to each speed bracket of DfT, total emission reductions can be estimated assuming certain rates of compliance. It is noted that this measure has an effect on

[56] Personal Communication with AEA Energy & Environment, 4th December 2007

many pollutants, including fuel and therefore CO_2, as well as wider benefits such as the potential to slow traffic growth, optimising current road network capacity and bringing significant safety benefits. It could however be a contentious political issue, although if it is demonstrated appropriately as a sophisticated approach to tackling a range of issues including health, safety and the environmental credentials it could gain in public acceptance.

CfIT (2007) included speed limit enforcement in a package of recommended measures, with more likely initial compliance rates of 50%, rising to 80%. Capital costs assume comprehensive blanket coverage of SPEC speed cameras (average speed check cameras), multiplied up from the manufacturer's equipment quote of £293,000 per 4.5km (Speedcheck, 2008). This figure is multiplied up to the entire motorway network of 3,555km (DfT, 2007), assuming 3 lanes per direction. No implementation costs are included as it is assumed that fines are revenue neutral, although they could be used to finance equipment costs. No valuation of safety benefits is made, although it is recognised that a reduction in average speed would lower the number of accidents (DfT, 2005). Other benefits such as air quality improvements are also not included. Against this high capital cost (to the Exchequer) is a considerable fuel saving operational negative cost (distributed among those who reduce their speed) due to improved fuel efficiency at lower speeds. This has been estimated from the resource cost of fuel (i.e. without tax), which is assumed to rise at 3% per year, to be annually ~£86m. Crude oil prices are at present highly volatile, and may further increase this figure. The social benefit from reduced CO_2 emissions has been excluded. The total calculated NOx saving from this measure in 2010 is 0.64 kt.

Variations and extensions of this measure include:

- Enforcement of the speed limit on dual carriageways and single carriageways;
- Enforcement extended to include all vehicles at their respective speed limits;
- A reduction in the speed limit, e.g. from 70mph to 60mph.

Transfer of freight from road to rail (measure N2.1)

This non-technical measure is based on the assumption that, per-tonne kilometre, the movement of goods by rail freight has reduced emissions compared with road freight (HGVs). It is assumed that rail freight offers NOx emission reductions of 82% over HGVs (SRA, 2005). No distinction is made between rigid and articulated HGVs. Furthermore, no assumption is made on the possible need for additional haulage by rail onwards from rail terminals to final destinations.

It is assumed that from 2008 the vehicle kilometres travelled by HGVs will be shifted from road to rail at an annual incrementing rate, i.e. total percentage each year will be 1% in 2008, 2% in 2009, 3% in 2010. The total calculated NOx saving from this measure in 2010 is 3.88 kt.

Due to lack of any quantitative data and the high uncertainties involved, no costs for this measure are provided.

Variations of the measure could consider altering the percentage switching from road to freight.

Retrofitting SCR to HDVs (measures T1.1 and T1.2)

This technical measure considers the retro-fitting application of Selective Catalytic Reduction (SCR) as an end-of-pipe exhaust measure for the in-service captive fleets of HDVs. SCR fitted to vehicles offers considerable NOx reduction potential, but at high capital and operating costs.

The operating costs are the re-supply of the reductant (urea or ammonia, assumed to be consumed at 6% of fuel consumption), and the capital costs include fitting and re-tuning of the engine. Per vehicle capital costs are assumed to be £7,500 and annual operating costs £430. Total costs are calculated from numbers of relevant vehicles. Fuel savings may be possible with additional engine re-tuning to lean burn, but this has not been possible to quantify and so zero impact on fuel economy is assumed (AEA, 2005). SCR can impact on emissions of other pollutants; these are not considered in this study for 2010 NOx.

Measure T1.1 includes both HGVs and buses, but at different uptake rates. Buses are assumed to be retrofitted quickly, at 20% per annum starting in 2008; HGVs are assumed to be retrofitted at 4% per annum, starting in 2008. The total calculated NOx saving from this measure in 2010 is 21.50 kt.

Measure T1.2 assumes that buses will be subject to other abatement measures and so considers only an annual incremental retrofitting of 4% for HGVs from 2008. The total calculated NOx saving from this measure in 2010 is 12.26 kt.

Variations of these measures could include:

- Altering the bus captive fleet uptake rate;
- Altering the HGV fleet uptake rate;
- Considering uptake by large diesel LGVs.

Retro-converting HDVs to use CNG (measure T2.1)

This technical measure considers the incentivised conversion of HDVs – both HGVs and buses – to run on compressed natural gas (CNG) instead of diesel. HDVs running on CNG are assumed to emit 85% less NOx than DERV-fuelled HDVs. CNG-converted vehicles also emit less CO, PM and CO_2, but CH_4 emissions increase. The fuel saving from using CNG results in the negative operating cost of £4,950 per vehicle; capital costs for conversion per vehicle are assumed to be high at £20,000 (AEA, 2005). Total costs are calculated from numbers of relevant vehicles. The fuel savings may seem very high, but it is the high capital cost and the restricted refuelling network which is preventing uptake. These costs do not include costs of building infrastructure or costs of longer journeys to refuel.

The measure assumes 0.4% of existing HDVs are converted to run on CNG per year, or approximately 2,000 vehicles total annually. The total calculated NOx saving from this measure in 2010 is 1.84 kt.

Variations of this measure could include:

- Altering the bus captive fleet uptake rate;
- Altering the HGV fleet uptake rate;
- Considering uptake by vehicles other than HDVs, such as LGVs;
- Conversion to other fossil-based fuels, e.g. liquid petroleum gas (LPG), or liquefied natural gas (LNG).

Replacement of existing vehicles with hybrids (measures T3.1 and T3.2)

This technical measure considers the use of hybrid vehicle technology to replace existing stock of vehicles. Hybrid vehicles pair a petrol or diesel internal combustion engine with an electric motor that is powered by on-board batteries which are charged by either regenerative braking or the engine. Hybrids offer reduced emissions of all exhaust pollutants, due to decreased use of the combustion engine. Hybrids are not suitable for HGVs due to the loads borne, but are successfully used for buses.

Measure T3.1 assumes an uptake of diesel-electric hybrid buses replacing existing diesel buses at a rate of 1% of fleet per annum (i.e., approximately 1000 buses per annum), starting from 2008. Current and BAU uptake of hybrid buses is low and no statistics were available on this and so has been assumed to be zero. Hybrid buses are assumed to offer an 80% NOx reduction, as compared to a Euro III bus. The high capital costs of £75,000 on top of an average bus is offset by negative annual operating costs (compared to a diesel bus) due to fuel savings (AEA, 2005). The total calculated NOx saving from this measure in 2010 is 0.57 kt.

Measure T3.2 assumes an uptake of electric hybrid cars replacing existing petrol and diesel cars at a rate of 0.5% each per annum (i.e., approximately 130,000 cars per annum), starting from 2008. Current and BAU uptake of hybrid cars is low and no statistics were available on this and so has been assumed to be zero. Hybrid cars are assumed to offer a 92% NOx reduction, as compared to a Euro IV car, calculated from VCA fleet data (VCA, 2007). The capital costs of £1,750 on top of an average car is offset by negative annual operating costs (compared to an average car) of £105 due to fuel savings (AEA, 2005). The total calculated NOx saving from this measure in 2010 is 1.92 kt.

Variations of these measures could include:

- Altering the bus captive fleet uptake rate;
- Altering the passenger car uptake rate.

Euro VI standard for HDVs (measures T4.1 and T4.2)

This technical measure considers the adoption of a Euro VI emission standard for HDVs. Although a Euro 6 standard for LDVs has been adopted in legislation and included in emission projections, a proposed Euro VI standard for HDVs is still under debate. In the recent consultation[57], four possible scenarios of sets of limit values for the Euro VI standard were presented; the present measures assume scenario A, i.e. a NOx reduction of 80% compared to a Euro V HDV (limit value 0.4g/kWh), equally for rigid and articulated HGVs and for buses. The additional capital cost of a Euro VI vehicle over a Euro V is assumed to be an average of low and high technology costs provided by Defra[58]; £615 per rigid HGV, £1250 per articulated HGV. Capital costs for Euro VI buses were assumed to be the average of the two HGV costs due to lack of further data. Defra indicated that no additional operating costs are anticipated in

57 http://ec.europa.eu/enterprise/automotive/pagesbackground/pollutant_emission/heavy_duty/public_consultation/index.htm

58 Personal communication with Defra on 28th November 2007

terms of additional reagent although a fuel penalty of approximately 6% relative to a Euro V HGV would be incurred.

The current Euro VI proposals indicate that the standard will come into force in 2013. As such, by this date all new HDVs sold on the market will have to be compliant with the standard, i.e. 100% compliance from 2013. It is assumed that prior to 2013 a proportion of new HDVs that are sold will be compliant in advance. For measure T4.1 this is assumed to be 5% in 2008, 15% in 2009, 30% in 2010, 60% in 2011 and 90% in 2012. The total calculated NOx saving from this measure in 2010 is 3.59 kt.

Due to imminent agreement of this future emission standard, an incentivised advanced uptake of Euro VI compliant HDVs is a beyond BAU abatement measure. This is assumed to be the case in measure T4.2, when the assumed uptake rates for new HDVs (as a proportion of new HDVs sold) are 15% in 2008, 30% in 2009, 60% in 2010, 90% in 2011 and 100% in 2012. Measure T4.1 has not been considered in the scenario analysis. The total calculated NOx saving from measure T4.2 in 2010 is 7.18 kt.

Possible variations of these measures include:

- The adoption of an alternative emission limit value for Euro VI;
- Altered uptake rate;
- Varied advanced uptake rates among buses, rigid HGVs and articulated HGVs.

Low emission vehicles (LEVs) (measure T5.1)

This is measure E from the 2007 Air Quality Strategy (AQS), updated to start from 2008 (Defra, 2007b). Low emission vehicles (LEVs) are defined to reduce NOx by 80% for diesel cars and 38% for petrol cars (compared to respective Euro IV standards) by meeting future emission standards well in advance of their implementation, but are technology-neutral. A measure to incentivise their early uptake assumes the replacement of non-LEV petrol cars with petrol LEVs, and replacement of non-LEV diesel cars with diesel LEVs.

The uptake for new petrol LEV cars is assumed to rise by 2% per annum from 2008 (i.e. reaching 6% in 2010) and the uptake for new diesel LEV cars is assumed to rise by 1% per annum from 2008 (i.e. reaching 3% in 2010). The costs are taken from the AQS, i.e. additional capital costs of £1200 per diesel LEV and £600 per petrol LEV, and adjusted to 2007 prices. Zero additional operating costs are assumed. The total calculated NOx saving from this measure in 2010 is 0.24 kt. Variations of this measure include specifying LEVs to achieve a higher level of abatement.

Number of vehicles/vehicle kilometres/fuel consumption affected by the scenarios

The number of vehicles (new or existing) that will need to install the different technologies by 2010 for each measure are presented in Table A8.4 below, and the vehicle kilometres that would be switched from road (HGVs) to rail freight are presented in Table A8.5. The results presented for the different years represent a ‘snapshot’ of the situation in that particular year.

For the technical measures, these have been calculated by applying the scenario uptake rates to the vehicle numbers for each respective year. For the non-technical measures, these have been calculated by applying the assumed percentage change in vehicles kilometres travelled (for example, switching from road to rail freight) or efficiency improvements from driving at slower speeds.

Table A8.4 Vehicle numbers affected in 2010 – Technical options

Scenario	Technology	Vehicle Type	New or existing	Vehicle numbers affected in 2010 (000s)
T1.1	SCR	HDVs	Existing	109
T1.2	SCR	HGVs	Existing	46
T2.1	CNG	HDVs	Existing	5.9
T3.1	Diesel-electric Hybrid	Buses	Existing	3.1
T3.2	Hybrid	Cars	Existing	378
T4.1	Euro VI	HDVs	New	13
T4.2	Euro VI	HDVs	New	26
T5.1	LEV	Cars	New	146

Table A8.5 Road freight (HGV) vehicle kilometres switched to rail (billion vehicle km)

Scenario	2010
N1.1	0.981

Within the timescales of the study, it has not been possible to estimate the costs associated with a switch from road (HGV) to rail freight. A literature review has highlighted the lack of consistent and comparable cost data for road and rail freight (for example, cost per tonne kilometre). Costs of rail freight transport vary considerably between regions depending upon the location of railways and drop-off/pick-up points and will often require some road transport at either end of a journey.

The emission reductions associated with a switch from road to rail freight have been estimated based on the assumption that the road freight reduced would be replaced by rail freight only, i.e. without any road transport required. The Strategic Rail Authority has estimated that rail freight transport emits only 18% of NOx of the equivalent road freight transport (emissions per tonne-kilometre). These figures have been used to estimate the emissions reductions associated with a switch from road to rail freight transport.

The speed enforcement measure assumes a reduction in fuel consumption of approximately 150 million litres of petrol and 100 million litres of diesel.

Summary of abatement efficiency and costs assumed for different technologies

Table A8.6 Abatement efficiencies and costs assumed for different road transport measures

Measures		Applicable measures	NOx abatement efficiency	Costs per vehicle		Lifetime of measure (years)
				Capital (£)[1]	Operating (£/y)	
Technical measures						
SCR for HDVs[2]		T1.1, T1.2	65%	7,500	430	8
Hybrid car[3]		T3.2	92%	1,750	-105	12
Hybrid bus[4]		T3.1	80%	75,000	-4,500	15
CNG for HDVs[5]		T2.1	85%	20,000	-4,950	8
Euro VI[6]	Rigid HGVs	T4.1, T4.2	80%	615	375	15
	Articulated HGVs	T4.1, T4.2	80%	1,250	1,015	15
	Buses	T4.1, T4.2	80%	932.5	695	15
LEVs[7]		T5.1	80% diesel	£1,200		-
		T5.1	38% petrol	£600		
Non-technical measures						
Enforcement of motorway speed limit for cars[8]		NT1.1	19%	-	-	-
Rail freight (compared to road freight)		NT2.1	82%	-	-	-

[1] Mid-range estimate where high and low values available.

[2] Capital costs updated from AEA (2005) with KleenAir (2006). Operating costs from AEA (2005). Lifetime of measure from AEA (2005).

[3] Additional capital cost on top of normal petrol or diesel car. Operating costs scaled according to capital price differential between hybrid bus and hybrid car (AEA, 2005). Lifetime of measure from AEA (2005).

[4] Abatement efficiency relative to Euro III bus. Capital cost is additional to normal bus. Negative operating costs due to fuel savings. Lifetime of measure from AEA (2005).

[5] Negative operating costs due to fuel savings. Average cost savings from CNG scenario in AEA (2005). Lifetime of measure from AEA (2005).

[6]Abatement efficiency relative to Euro V - based on scenario A from http://ec.europa.eu/enterprise/automotive/pagesbackground/pollutant_emission/heavy_duty/public_consultation/index.htm, costs from Defra (Pers. Comm. 28/11/07). Lifetime of measure from GAINS (2008).

[7] Measure from the AQS (Defra, 2007b). Abatement efficiency is compared to a Euro IV car.

[8] Reduction in average speed of those breaking the speed limit (77.98mph) to 70mph.

A.8.3.3 Summary of Measures and Costs

Table A8.7 summarises the measures, their efficiencies and abatement potential for 2010 and their total annualised costs.

Table A8.7 Summary of NOx 2010 beyond business as usual abatement measures for road transport

Measure	Emission reduction efficiency (%) of measure	Future uptake of measure % (for 2010)	Operating life (years)	Reduction in 2010 emissions (kt)	Capital Costs (£k, 2007 prices)[2]	Annualised Capital Costs (£k)	Annual operating costs (£k, 2007 prices)	Total annualised costs (£kpa, 2007 prices)
T1.1 (SCR for HDVs)	65%	8%	8	21.5	856,131	124,547	49,085	173,632
T1.2 (SCR for HGVs)	65%	5%	8	12.3	365,868	53,225	20,976	74,202
T2.1 (CNG)	85%	1%	8	1.8	123,712	17,997	-30,619	-12,622
T3.1 (Hybrid buses)	80%	0%	15	0.6	245,132	21,284	-14,708	6,576
T3.2 (Hybrid cars)	92%	1%	12	1.9	694,146	71,833	-41,649	30,184
T4.1 (Euro VI)	80%	1%	15	3.6	12,008	1,043	8,366	9,409
T4.2 (Advanced uptake of Euro VI)	80%	2%	15	7.2	24,017	2,085	16,732	18,818
T5.1 (LEVs)[1]	59%[2]	0.10%	12	0.2	138,321	14,314	0	14,314
N1.1 (Speed limit enforcement)	3.77%	19%	15.0	0.6	694,410	60,292	-85,779	-25,486
N2.1 (Rail freight)	82%	82%	-	3.9	-	-	-	-

[1] The costs for this measure have been updated to take into account the altered uptake of the measure, hence will not agree with the AQSR costs

[2] Derived from 80% diesel and 38% petrol emission reduction efficiency

A.8.4 References

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A.9. Other mobile sources and machinery

A.9.1 Sector Profile

Table A9.1 presents the 2010 NOx emissions for agricultural and industrial off-road machinery developed by AEA[59], based on the BERR UEP 30 forecasts (DTI, 2007)) and the 2005 National Atmospheric Emission Inventory (NAEI).

Table A9.1 2010 NOx emissions for agricultural and industrial off-road machinery

SnapID	Source Name	Activity Name	Projection Year	Emissions (kt)
806	Agriculture - mobile machinery	Gas oil	2010	27.27
806	Agriculture - mobile machinery	Petrol	2010	0.00
808	Industrial off-road mobile machinery	Gas oil	2010	69.25
808	Industrial off-road mobile machinery	Petrol	2010	1.08

AEA[60] also provided aggregated 2010 NOx emission and activity data per Stage control, presented in Table A9.2.

Table A9.2 2010 NOx emission and activity data per Stage control for off-road transport

Source Name	Fuel	Stage	Emissions (kt)	Activity (kWhr/1E9)
Industrial off-road mobile machinery	Gas oil	Pre-Stage I	25.508	2.106
		Stage I	3.311	0.360
		Stage II	29.011	4.191
		Stage IIIA	10.536	3.149
		Stage IIIB	0.886	0.335
Industrial off-road mobile machinery	Petrol	Pre-Stage I	0.592	0.163
		Stage I	0.000	0.000
		Stage II	0.490	0.135

59 Personal Communication with AEA Energy & Environment, 12th November 2007

60 Personal Communication with AEA Energy & Environment, 7th December 2007

Source Name	Fuel	Stage	Emissions (kt)	Activity (kWhr/1E9)
Agriculture - mobile machinery	Gas oil	Pre-Stage I	7.145	0.496
		Stage I	7.717	0.839
		Stage II	5.848	0.975
		Stage IIIA	6.564	1.875
		Stage IIIB	0.000	0.000
		Stage IV	0.000	0.000

A.9.2 Business as Usual Policies and Abatement Techniques

Directive 2002/88/EC[61] and Directive 97/68/EC, relating to measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery, implement two stages of emission limit values for compression ignition engines. The two stages of emissions limits for new diesel engines set the maximum allowable emissions of NOx, PM, hydrocarbons and carbon monoxide. Stage I is already in force for all engine categories and Stage II has now entered into force for almost all engines. The emission limits are shown in Table A9.3

Directive 2004/26/EC of the European Parliament and of the Council amending Directive 97/68/EC, implements 3 stages of future emissions limits (Stage IIIA, IIIB & IV) that apply to equipment already within the scope of Directive 97/68/EC. The emission limits are shown in Table A9.4. In addition emission limits are introduced for commercial inland shipping engines and rail engines.

Directive 2000/25/EC[62] on measures against the emission of gaseous and particulate pollutants by engines intended to power agricultural and forestry tractors contains similar limits to Directive 97/68.

[61] Directive 2002/88/EC, amends Directive 97/68/EC

[62] Amended by Directive 2005/13/EC

Table A9.3 Emission limits in Directive 97/68/EC on non-road mobile machinery

Net Power, KW	Stage	Emission limit – CO – g/kWh	Emission limit – HC – g/kWh	Emission limit – NOx – g/kWh	Emission limit – particulates – g/kWh
130 – 560	I	5.0	1.3	9.2	0.54
	II	3.5	1.0	6.0	0.2
75 – 130	I	5.0	1.3	9.2	0.7
	II	5.0	1.0	6.0	0.3
37 – 75	I	6.5	1.3	9.2	0.85
	II	5.0	1.3	7.0	0.4
18 – 37	II	5.5	1.5	8.0	0.8

Table A9.4 Emission limits in Directive 2004/26/EC for engines for use in applications other than propulsion of inland waterway vessels, locomotives and railcars

Net Power, KW	Stage	Emission limit – CO – g/kWh	Emission limit – HC & NOx – g/kWh	Emission limit – HC – g/kWh	Emission limit – NOx – g/kWh	Emission limit – particulates – g/kWh
130 – 560	IIIA	3.5	4.0	-	-	0.2
	IIIB	3.5	-	0.19	2.0	0.025
	IV	3.5	0.19		0.4	0.025
75 – 130	IIIA	5.0	4.0	-	-	0.3
	IIIB	5.0	-	0.19	3.3	0.025
56 – 75	IIIA	5.0	4.7	-	-	0.4
	IIIB	5.0	-	0.19	3.3	0.025
56 – 130	IV	5.0	0.19		0.4	0.025
37 – 56	IIIA	5.5	7.5	-	-	0.6
	IIIB	5.0	4.7	-	-	0.025

A.9.3 Beyond Business as Usual

A.9.3.1 Abatement Techniques

Two abatement measures have been considered as beyond BAU measures for 2010;

- the additional uptake of Stage II controls (a 2 % uptake by new engines by 2010);

- the early uptake of Stage IIIA controls (a 15 % uptake by new engines by 2010).

A.9.3.2 Methodology/Assumptions

Within the timescales of this study it was not possible to obtain disaggregated data on this sector in order to analyse and develop measures as per the road transport sector. However, AEA[63] provided aggregated 2010 NOx emission and activity data per Stage control, presented in Table A9.2, that has allowed the development of beyond BAU measures, more specifically potential uptake of the measures and emission reductions. However, it should be noted that the potential uptake, emission reductions and costs presented for this sector are highly uncertain, since they have been developed based on only limited data.

By dividing emissions with activity, an average emission factor in g/kWhr can be derived. Based on these emission factors, the emission reductions that could be achieved in 2010 from the additional uptake of Stage II controls and the early uptake of Stage IIIA controls have been estimated, as shown in Table A9.5.

It has been reported that approximately 8% (7-9%) of emissions from the Non-Road Mobile Machinery (NRMM) inventory have an engine power bigger that 560kW and that 1% of emissions have an engine power below 19kW (EC, 2007) in a European scale. Therefore, assuming that approximately 9% from the AEA agricultural and industrial off-road machinery emission projections, are attributed to an engine with a power bigger that 560kW or lower than 19kW, and hence, do not have an emission limit value under the NRMM Directives then it can be estimated that 9.3kt of NOx emissions will not be affected by the proposed measures. Assuming that these emissions should be assigned to pre-stage I controls, the maximum uptake of the measures was estimated.

Table A9.5 Emission reduction efficiency and uptake of measures

Stage Controls	Estimated Emission Factors (g/kWhr)	Emission reduction efficiency (%) of measure for achieving Stage II	Maximum beyond BAU uptake of measure %	Assumed beyond BAU uptake of measure % (for 2010)
Pre-Stage I	12.0	45%	14%	0%[1]
Stage I	9.2	28%	8%	2%
Stage Controls	**Estimated Emission Factors (g/kWhr)**	**Emission reduction efficiency (%) of measure for achieving Stage IIIA**	**Maximum uptake of measure %**	**Assumed uptake of measure % (for 2010)**
All Stages	8.6	60%	58%	15%

[1] Due to the uncertainty related to the contribution of engines with a power bigger that 560kW or lower than 19kW

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[63] Personal Communication with AEA Energy & Environment, 7th December 2007

Costs for an additional uptake of Stage II controls are estimated based on a Regulatory Impact Assessment for Directive 2002/88/EC by the Department for Transport. If all the costs are allocated to one pollutant, regulation of constant speed diesel engines has been estimated to have a cost effectiveness of £856/t if allocated to NOx (or £3932/t if allocated to PM). (DfT, 2004)

Costs for an early uptake of Stage IIIA controls are estimated based on a Regulatory Impact Assessment for Directive 2004/26/EC by the Department for Transport (DfT, 2006). The RIA presents a cost effectiveness of £850 – 1620/t based on the cost of replacing the entire fleet, and the lifetime emissions savings from a compliant fleet of machinery.

A.9.3.3 Summary of Measures and Costs

Table A8.7 summarises the measures, their efficiencies and abatement potential for 2010 and their total annualised costs.

Table A9.6 Summary of NOx 2010 beyond business as usual abatement measures for agricultural and industrial off-road machinery

Measure	Emission reduction efficiency (%) of measure	Future uptake of measure % (for 2010)	Operating life (years)	Reduction in 2010 emissions (kt)	Capital Costs (£k, 2007 prices)[2]	Annualised Capital Costs (£k)	Annual operating costs (£k, 2007 prices)	Total annualised costs (£kpa, 2007 prices)
Further uptake of Stage II controls	28%	2%	-	0.1	-	-	-	58
Early uptake of Stage IIIA controls	60%	15%	-	7.2	-	-	-	9,628

A.9.4 References

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