DEFRA

Multi Pollutant Measures Database (MPMD): Extension to 2030

Draft Final Report

AMEC Environment & Infrastructure UK Limited

September 2012

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Document Revisions

No.	Details	Date
1	Draft final report for client comment	04/09/2012

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UK Limited

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Doc Reg No. 31772

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Certificate No. FS 13881

Certificate No. EMS 69090

Glossary

AQSR	Air Quality Strategy Review
BAU	Business as Usual
CNG	Compressed Natural Gas
COG	Coke Oven Gas
DPF	Diesel Particulate Filter
ECB	European Central Bank
ESI	Electricity Supply Industry
ESP	Electrostatic Precipitators
FGD	Flue Gas Desulphurisation
GAINS	Greenhouse Gas and Air Pollution Interactions and Synergies
HDV	Heavy Duty Vehicles
IGCC	Integrated Gasification Combined Cycle
kt	kilotonnes
LDAR	Leak Detection And Repair
LDV	Light Duty Vehicles
LGV	Light Goods Vehicles
NAEI	National Atmospheric Emissions Inventory
NECD	National Emission Ceilings Directive
NH_3	Ammonia
VOCs	Volatile Organic Compounds
NOx	Nitrogen Oxides
$PM_{2.5}$	Particulate Matter with an aerodynamic diameter of less than 2.5µm
PV	Photovoltaic
PVR	Petrol Vapour Recovery
SCR	Selective Catalytic Reduction
SNCR	Selective Non-Catalytic Reduction
SO_2	Sulphur Dioxide
VRU	VOC Recovery Units

Executive Summary

The purpose of this overall programme of work is to develop a database of measures beyond those expected to be implemented under business as usual (BAU) policies for reducing emissions of air pollutants. A key feature of this work is that the impact on all key air pollutants is considered, in order to more fully assess the benefits of such measures. The database of measures is intended to provide supporting information for the consideration of future policies such as a revised National Emission Ceilings Directive (NECD). Therefore the main focus of the analysis has been on those pollutants regulated – or expected to be in the future – under the NECD (NOx, SO_2, PM2.5 and VOCs). Beyond BAU measures for ammonia have been developed by another Defra contractor and therefore have not been included in this report.

Existing versions of the Multi-Pollutant Measures Database (MPMD) have focussed on developing beyond BAU measures for reducing emissions in 2020. Due to a number of delays in the NECD revision process it now appears likely that any future NECs will apply from after 2020 e.g. 2025 and/or 2030. Therefore, Defra has recognised a need to update and extend the MPMD up to 2030. This report provides a summary of the work that has been undertaken to extend the MPMD to 2025 and 2030 including the updating of existing measures (with the latest emission projections) and development of new measures. Further details of the measures developed for each sector are provided in sector specific appendices.

The scope of this work package did not include a complete overhaul and update of existing MPMD measures (i.e. those for 2020); these were updated with new emission projections but changes to other assumptions were only made where necessary. However, new measures were also developed for those sources which were expected to be significant emitters in 2030 but had not been considered in any detail previously.

It is anticipated that the next stage of this work stream will be the development of compliance scenarios for the potential revised NECD. A series of least cost compliance scenarios (cost curves for each pollutant) and/or alternative scenarios will be developed in order to indicate the ways in which the UK could meet the potential ceilings and associated costs.

Contents

Appendix A Sector Analysis

1. Introduction

1.1 Purpose of this Report

The aim of the Multi-Pollutant Measures Database (MPMD) study is to develop a database of measures beyond those expected to be implemented under business as usual (BAU) policies for reducing emissions of air pollutants. To date, potential beyond BAU measures for 2020 have been developed for the highest emitting sectors including associated costs and emission reductions. The database of measures is intended to provide supporting information for the consideration of future policies such as a revised National Emission Ceilings Directive (NECD). Therefore the main focus of the analysis has been on those pollutants regulated – or expected to be in the future – under the NECD (NOx, SO_2, PM2.5 and VOCs). Beyond BAU measures for ammonia have been developed by another Defra contractor and therefore have not been included in this report.

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1.2 Background

1.2.1 MPMD developments

The multi-pollutant measures database (MPMD) was first developed during 2008. A number of the measures included in this report were first developed at that time. In August 2009 an updated report was published in which the measures were updated using the UK emission projections based on the 2007 NAEI and ‘UEP32’ energy baseline developed by DECC combined with a series of assumptions for each sector . The information on policies and abatement techniques given in the August 2009 report was updated in line with these assumptions, where sufficient information was available from AEA.

In October 2010 the UK emission projections were updated to reflect the 2008 NAEI and ‘UEP38’ energy baseline. These projections were used to update the MPMD although information on policies and abatement techniques were not updated at the time, except for the addition of nuclear new build as an alternative measure to coal new build.

In November 2011 adjustments were made to measures to reflect comments received from Defra, DECC, the Environment Agency, AEA and Imperial College's UKIAM team, on single pollutant cost curves developed using the MPMD. Changes were made to a number of the power sector measures and a new measure for conversion from coal to biomass was added.

As part of this study, a scoping study was undertaken to identify the UK's highest emitting sectors in 2030 for which abatement measures should be investigated for inclusion in the MPMD. A draft[1] version of the National Atmospheric Emission Inventory (NAEI) emission projections for 2030, based on DECC's Updated Energy Projections (UEP43), was reviewed to identify the sectors contributing to at least one percent of total UK emissions (excluding road transport emissions[2]). The outcome of the scoping study was discussed with Defra at a meeting on 13 January 2012 in order to agree on the sectors to be investigated; further details on the sectors selected for investigation are provided in Section 2.3.

1.2.2 National Emission Ceilings Directive (2001/81/EC)

The National Emission Ceilings Directive (NECD, 2001/81/EC)[3] 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 (SO_2), nitrogen oxides (NO_x), 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 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.

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[1] AEA, Emissions_2010&2015&2020 UEP43 CCC, Dated 12/12/2011

[2] Road transport emissions were not included in the projections provided and therefore not included in the UK total emissions used for this screening assessment.

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

1.2.3 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 in future years (possibly 2025 and/or 2030) 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[4]. The Commission has previously 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 NECD proposal was originally planned for adoption by the Commission in July 2007 but has since been delayed. The Commission is now not expected to propose a revised Directive including emission ceilings in 2013, although exact timescales are yet to be confirmed.

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 beyond BAU abatement measures developed;
- Section 4 presents the main uncertainties and limitations associated with the MPMD.

Information on the underlying data, assumptions, and methods used to develop the database of measures is provided in the Appendices on a sector-by-sector basis.

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

2. Methodology

2.1 Introduction

This section summarises the methodology used to prioritise new sectors, to select potential abatement measures to reduce pollutant emissions covered by the NECD and determine their possible uptake, costs and abatement efficiencies. Existing measures within previous versions of the MPMD have been updated to 2025 and 2030 using the latest NAEI UEP43 emission projections. Cost data and other assumptions have only been updated for existing measures where necessary.

2.2 Emission projections

The UK National Atmospheric Emissions Inventory (NAEI) projections (AEA, 2012) provides estimates of projected atmospheric releases of NOx, SO_2, PM_{10}, $PM_{2.5}$, NMVOCs, NH_3 and other pollutants up to 2030, as summarised in the table below.

Table 2.1 BAU emission projections (kt) for sources covered under the NECD

Year	NOx (kt)	SO2 (kt)	PM10 (kt)	PM2.5 (kt)	NMVOC (kt)	NH_3 (kt)
2010	735	431	109	54	701	284
2020	490	274	102	49	664	284
2025	437	242	103	49	665	289
2030	419	236	105	50	671	294

Source: Taken from file AMEC_UEP43CCC_25042012 (except ammonia projections which have been taken from AEA 2012, draft).

The UK emission projections are based on the 2009 NAEI developed by AEA and the ‘UEP43’ energy baseline developed by DECC combined with a series of assumptions for each sector[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. However, in some instances we have identified areas within the projections that would benefit from review and possible improvements in future editions. These will be discussed with Defra and the NAEI team separately.

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[5] Key assumptions presented in AEA Group (2012): 2012 Air Quality Emission Projections. A report of the National Atmospheric Emissions Inventory, March 2012 [DRAFT].

2.3 Selection of additional emission sources

The emission sources considered for developing additional potential abatement measures were determined based on their contribution to the total projected UK emissions per pollutant in 2030 (those over 3% were considered to be a priority and have all been considered, whilst in most cases those over 1% were also considered; for PM any sources contributing over 0.1% of total emissions in 2030 have been reviewed). The scope of the MPMD has always been to identify the most promising abatement measures for the most polluting sectors. It is not an all encompassing review of every possible abatement measure.

2.4 Development of abatement measures

Abatement measures have been developed and presented in a database of beyond BAU measures based on a range of information sources including:

- Consultation with an extensive range of stakeholders (including equipment manufacturers, operators and sector associations, Government Departments etc);
- Reference Documents on Best Available Techniques for specific sectors;
- Reports developed by Entec under the Defra contract “Cost Curves for Air Pollutants” (April 2002 to March 2005);
- Earlier versions of the MPMD and supporting reports (2008, 2011); and
- Other published information sources.

A series of bilaterals were held in 2008 with selected sector associations and other relevant stakeholders to discuss the study, understand the BAU situation and to gather data on costs, abatement efficiencies and related information on potential beyond BAU measures (i.e. the Association of Electricity Producers and various of their members, the Society of Motor Manufacturers and Traders, the Department for Transport, the British Cement Association and a few of their members and Corus).

Additionally, the draft report was circulated for stakeholder consultation in 2008. The aim of this consultation was to understand if the measures developed are commercially/technically feasible and to confirm that the assumed characteristics such as abatement efficiency and applicability presented in the report are realistic and the costs accurate. In addition, it was used to ensure that the assumed BAU uptake of specific measures is accurate and that the BBAU measures developed take this into account (i.e. to ensure no double counting of measures and their potential emission reductions and/or exclusion of relevant measures if they have been incorrectly assumed to be fully implemented under BAU commitments).

Parameters within the database include;

- Description of the sector, fuel and measure;
- Uptake by the sector (under BAU policies and potential scope for additional ‘beyond BAU’ uptake for 2025 and 2030);
- Emission reduction efficiency for the NEC pollutants, PM10/PM2.5 and greenhouse gases;
- Operating life of measure within sector;
- Capital and operating costs;
- Total annualised cost.

In total, 185 separate measures (or variations around a single measure) have been developed and are presented in the database. Table 2.2 lists the measures that have been developed broken down by sector; these are described in more detail in the Appendices.

Table 2.2 Overview of measures developed in this study

Sector	Measure
Power Stations	• Additional field of ESPs • Increase of existing FGD efficiency from 90% to 92.5% (chemical additives) or to 95% (addition of more spray banks in scrubbing process) • SCR • Closure of older plants & replacement with more efficient new plants (with and without SCR) • New build as IGCC with pre-combustion post 2015 • New build as PC with oxyfuel post 2015 • New build as PC with post combustion CCS by 2020 • Increased biomass co-firing (co-milling or direct injection) • Switch from coal to 100% biomass firing • Large-scale CHP for community heating • New build coal replaced by new build nuclear • Low sulphur coal (from UK average of 0.91% to UK average of 0.51%) • Close existing coal and open nuclear • Close existing CCGT and open nuclear • New nuclear instead of CCGT • New renewables (non-thermal) build instead of coal or CCGT • Close existing coal or CCGT and open renewables (non thermal)

Sector	**Measure**
Autogenerators	• ESP (from other combustion) • Low sulphur coal (from UK average of 0.91% to UK average of 0.51%) • Retrofit SCR • Coal Closure and reopen CCGT with or without SCR • Increased biomass co-firing (co-milling or direct injection) • Biomass conversion • Close existing CCGT and open renewables (non-thermal) • ESP (from other combustion)
Road transport	• Retrofit DPF (full wall-flow) to pre-Euro VI existing HDVs • New hydrogen fuel cell buses instead of new diesel buses • Replace existing pre-Euro VI buses with hybrid buses • Incentivise new hybrid buses instead of diesel buses • Replace existing pre-Euro 6 diesel LGVs with hybrid LGVs • Replace existing pre-Euro 6 petrol cars with hybrid cars • Replace existing pre-Euro 6 diesel cars with hybrid cars • Sealed wet brake retrofit (HGVs, LGVs, cars and buses) • Ecodriving (driver training programme to target existing drivers) and application of gear shift indicators • Motorway speed limit enforcement • Downsizing petrol cars • Replace existing pre-Euro 6 petrol or diesel cars with electric cars and incentivise new electric vehicles • Replace existing pre-Euro 6 diesel LGVs with electric LGVs • Replace existing pre-Euro VI buses with electric buses • Road spraying • Shift of road freight to rail freight
Coke production	• SCR
Coke Oven Gas (COG)	• COG Desulphurisation by absorption system
Iron & steel	• COG desulphurisation • SCR • ESP • Bag filters • Dry or wet dedusting (ESP or scrubber) • Enclosure
Sinter production	• SCR • Regenerative activated carbon (RAC) • Partial Gas Recycling • Bag (fabric or metallic mesh) filter with or without flow-injection • Advanced ESP
Refineries	• Switch to natural gas (no pipeline) • SCR • SNCR • Wet scrubber

Sector	**Measure**
Oil and gas	• Vapour recovery unit • Modification to floating production • Modification to shuttle tankers • Dry Low NOx • Improved ignition system on flares
Other industrial combustion	• Low Sulphur coal (0.6%S) • Low Sulphur oil (0.6%S) • Combustion modification with and without SCR or SNCR • ESP stage 1
Aluminium	• Inert anodes retrofit • Wet scrubber
Animal carcass incineration	• Extension of Part B regulation
Glass	• Ceramic filter
Industrial adhesives	• Substitution • Abatement of emissions through incineration
Dry cleaning	• New installations - water cleaning
Agrochemicals	• New products
Domestic products	• Stage 1, 2 & 3 reformulation
Organic chemicals	• Internal floating covers/sec.seals, vapour recovery (double stage) • Vapour recovery unit (double stage) • LDAR Stages 2, 3 and 4
Industrial coatings	• Powder coating systems • Low, high and very high solids coating systems
Other food	• Schumacher type desolventiser plus old hexane recovery
Domestic Combustion	• Homes heated with natural gas switch to using heat pumps • Fuel switching from coal/oil to electricity/natural gas • Increased uptake of: – Insulation – A Rated Boilers – Solar water heating – PV electricity – District heating – Small CHP / biomass
Brick manufacture	• Dry scrubber for Fletton brick manufacture
Railways	• Electrification of certain lines • DPF retrofit

Sector	Measure
Shipping – coastal	• Slide valves • Direct Water Injection (DWI) • Charge air humidification • Waste heat recovery • SCR • Sea water scrubbing • Fuel switch to LNG • Water-diesel emulsion • Biodiesel or plant oil • Kite • DPF
Aviation	• Optimise LTO practice* / Derated take-off* • Early Aircraft retirement
Intensive livestock housing	• Oil spraying • Single chemical scrubber • Single, two and three stage scrubbers • Two step biological scrubber
Petrol stations	• Extension of Stage II PVR
Fugitive PM emissions (relevant to number of sources)	• Combined PM abatement measures
Other mobile sources	• Retrofitting DPFs to >37kW agricultural & industrial off-road machinery • Retrofitting DPFs to <37kW industrial off-road machinery • Retrofitting SCR to >56kW agricultural & industrial off-road machinery • Introducing Stage control limits for <19kW for industrial off-road machinery
Cement & lime	• SNCR • Wet Scrubber • Absorbent Addition

Note 1: Measures specifically aimed at reducing NH_3 emissions are being developed by a separate contractor for Defra.

It is important to note that these measures have been developed from a technical perspective and the actual way in which they could potentially be implemented in practice has not been considered in any detail. In addition, it was not within the scope of this study to assess the economic impacts of the measures considered including impacts on competition and competitiveness.

In addition, a number of additional sectors have been reviewed as part of this work but for various reasons no beyond BAU measures have been developed. Reasons for this include sectors made up of multiple smaller sources making it difficult to control (e.g. small scale waste burning), sectors which will already be applying the best available techniques by 2030 and sectors where it has not been feasible within the scope and timescales of the study to identify sufficient data to develop possible abatement measures.

2.5 Costing

The methodology for the standardisation of the cost estimates is shown in Table 2.3 below[6].

Table 2.3 Rules for the standardisation of cost estimates

Category	Standardised approach
Prices and inflation	Price estimates have been presented in 2011 prices. 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.ons.gov.uk/ons/publications/re-reference-tables.html?edition=tcm%3A77-233930 This approach was agreed in consultation with Defra and is consistent with that used in previous versions of the MPMD.
Exchange rates	The ECB Statistical data warehouse containing historical exchange rates has been used to convert cost estimates quoted in euros (or other currencies) 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 the Appendices for each measure.

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

3. Overview of Beyond BAU Measures Developed

Table 3.1 presents all the beyond BAU abatement measures developed, which are presented in more detail at a sectoral level in the Appendices. Costs and emission reductions are presented for 2030 but impacts in 2025 have also been calculated.

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 will be taken into account for the development of the compliance scenarios.

Table 3.1 Summary of beyond BAU measures developed, their costs and associated emission reductions for 2030

ID	Sector	Measure Description	Total Annualised Cost £kpa	Emission reduction NOx (kt)	Emission reduction SO_2 (kt)	Emission reduction PM10 (kt)	Emission reduction PM2.5 (kt)	Emission reduction VOC (kt)
1	Power Stations	Additional ESP field	7,517			0.14	0.06	
2	Power Stations	Low sulphur coal (from UK average of 0.91% to UK average of 0.51%)	17,854		4.78			
3	Power Stations	Improved FGD (additional spray banks in the scrubbing process)	6,053		2.58			
4	Power Stations	Improved FGD (chemical additives)	5,546		1.25			
5	Power Stations	Retrofit SCR	9,172	1.23				
6	Power Stations	SCR retrofit to CCGT (JEP) (75% uptake)	264,308	15.86				
7	Power Stations	Coal Closure and reopen CCGT (50% uptake)	242,817	1.41	2.23	0.06	0.03	
8	Power Stations	Coal Closure and reopen CCGT with SCR (50% uptake)	257,208	2.49	2.23	0.06	0.03	
9	Power Stations	New build as IGCC with pre-combustion capture (CCS)	341,883	1.58	0.77			
10	Power Stations	New build as PC with oxyfuel (CCS)	234,257	1.97	1.59	0.04	0.02	
11	Power Stations	New build as PC with post-combustion CCS	237,824	0.70	1.75	-0.01	0.00	
12	Power Stations	Increased biomass co-firing (co-milling)	45,662		0.62			
13	Power Stations	Increased biomass co-firing (direct injection)	109,337		1.25			
14	Power Stations	Biomass conversion	453,216		4.61			
15	Power Stations	Large scale CHP for community heating	405,790	0.31				

ID	Sector	Measure Description	Total Annualised Cost £kpa	Emission reduction NOx (kt)	Emission reduction SO_2 (kt)	Emission reduction PM10 (kt)	Emission reduction PM2.5 (kt)	Emission reduction VOC (kt)
16	Power Stations	New nuclear build instead of coal	-110,480	2.16	1.74	0.05	0.02	
17	Power Stations	Close existing coal and open nuclear	-34,721	5.45	4.40	0.12	0.05	
18	Power Stations	Close existing CCGT and open nuclear	-2,477,659	17.69	-0.15	-0.08	-0.08	
19	Power Stations	New nuclear instead of CCGT	-2,995,973	7.76	-0.09	-0.03	-0.03	
20	Power Stations	New renewables (non-thermal) build instead of coal	-63,163	2.19	1.77	0.05	0.02	
21	Power Stations	Close existing coal and open renewables (non thermal)	132,064	5.53	4.46	0.12	0.05	
22	Power Stations	Close existing CCGT and open renewables (non-thermal)	-941,686	17.69	0.34	0.44	0.44	
23	Power Stations	New renewables (non-thermal) instead of CCGT	-779,257	7.76	0.15	0.19	0.19	
24	Autogenerators	ESP (from other combustion)	739			0.33	0.18	
25	Autogenerators	Low sulphur coal (from UK average of 0.91% to UK average of 0.51%)	35,962		9.83			
27	Autogenerators	Retrofit SCR	10,603	5.85				
28	Autogenerators	Coal Closure and reopen CCGT (50% uptake)	61,199	3.72	22.44	0.35	0.18	
29	Autogenerators	Coal Closure and reopen CCGT with SCR (50% uptake)	66,751	6.59	22.44	0.35	0.18	
30	Autogenerators	Increased biomass co-firing (co-milling)	15,859		22.44			
31	Autogenerators	Increased biomass co-firing (direct injection)	28,431		22.44			
32	Autogenerators	Biomass conversion	43,839		22.44			
33	Autogenerators	SCR retrofit to CCGT (JEP) (75% uptake)	83,245	10.11				

ID	Sector	Measure Description	Total Annualised Cost £kpa	Emission reduction NOx (kt)	Emission reduction SO_2 (kt)	Emission reduction PM10 (kt)	Emission reduction PM2.5 (kt)	Emission reduction VOC (kt)
34	Autogenerators	Close existing CCGT and open renewables (non-thermal)	-1,366,715	16.85		0.16	0.16	
35	Autogenerators	ESP (from other combustion)	335			0.15	0.16	
36	Road transport	Retrofit DPF (full wall-flow) to pre-Euro VI existing HDVs	3,174			0.00	0.00	0.00
37	Road transport	New hydrogen fuel cell buses instead of new diesel buses (low)	7,939	0.01		0.00	0.00	0.00
38	Road transport	New hydrogen fuel cell buses instead of new diesel buses (high)	11,644	0.01		0.00	0.00	0.00
39	Road transport	Combined effect Replace existing pre-Euro VI buses with hybrid buses (high)	60,133	0.03		0.02	0.01	
39L	Road transport	Combined effect Replace existing pre-Euro VI buses with hybrid buses (low)	30,066	0.03		0.01	0.00	
40	Road transport	Combined effect Incentivise new hybrid buses instead of diesel buses (high)	19,469			0.00	0.00	
40L	Road transport	Combined effect Incentivise new hybrid buses instead of diesel buses (low)	9,735			0.00	0.00	
41	Road transport	Combined effect Replace existing pre-Euro 6 diesel LGVs with hybrid LGVs	50,535	0.00		0.13	0.05	0.01
42	Road transport	Combined effect Replace existing pre-Euro 6 petrol cars with hybrid cars	794	0.03		0.18	0.07	0.02
43	Road transport	Combined effect Replace existing pre-Euro 6 diesel cars with hybrid cars	6,749	0.62		0.23	0.09	
44	Road transport	Sealed wet brake retrofit (HGVs)	410,950			0.56	0.22	
45	Road transport	Sealed wet brake retrofit (LGVs)	2,284,299			0.80	0.32	
46	Road transport	Sealed wet brake retrofit (cars)	991,982			1.32	0.53	

ID	Sector	Measure Description	Total Annualised Cost £kpa	Emission reduction NOx (kt)	Emission reduction SO_2 (kt)	Emission reduction PM10 (kt)	Emission reduction PM2.5 (kt)	Emission reduction VOC (kt)
47	Road transport	Sealed wet brake retrofit (buses)	11,997			0.14	0.06	
49	Road transport	Ecodriving (driver training programme to target existing drivers) and application of gear shift indicators to ensure continued benefits	-188,901,740	-3.06	0.00	0.05	0.02	
50	Road transport	Ecodriving for HGVs (high ambition)	-129,550	-0.66	0.00	0.02	0.01	
50L	Road transport	Ecodriving for HGVs (low ambition)	-97,163	-0.49	0.00	0.02	0.01	
51	Road transport	Ecodriving for LGVs (high ambition)	-86,055	-1.30	0.00	0.02	0.01	
51L	Road transport	Ecodriving for LGVs (low ambition)	-43,028	-0.65	0.00	0.01	0.00	
52	Road transport	Motorway speed limit enforcement	-31,450	1.18		0.00	0.00	
53	Road transport	Downsizing petrol cars (high)	-4,609,987	0.74		0.03	0.02	
53L	Road transport	Downsizing petrol cars (low)	-2,304,993	0.37		0.01	0.01	
54	Road transport	Combined effect Replace existing pre-Euro 6 petrol cars with electric cars and incentivise new electric vehicles (high)	123,020	0.04	-0.01	0.00	0.00	0.06
54L	Road transport	Combined effect Replace existing pre-Euro 6 petrol cars with electric cars and incentivise new electric vehicles (low)	64,565	0.03	0.00	0.00	0.00	0.04
55	Road transport	Combined effect Replace existing pre-Euro 6 diesel cars with electric cars and incentivise new electric vehicles (high)	124,416	0.44	-0.01	0.00	0.00	0.07
55L	Road transport	Combined effect Replace existing pre-Euro 6 diesel cars with electric cars and incentivise new electric vehicles (low)	63,235	0.26	-0.01	0.00	0.00	0.04
56	Road transport	Combined effect Replace existing pre-Euro 6 diesel LGVs with electric LGVs (high)	127,498	0.24	-0.01	0.00	0.00	0.08

ID	Sector	Measure Description	Total Annualised Cost £kpa	Emission reduction NOx (kt)	Emission reduction SO_2 (kt)	Emission reduction PM10 (kt)	Emission reduction PM2.5 (kt)	Emission reduction VOC (kt)
57	Road transport	Combined effect Replace existing pre-Euro VI buses with electric buses (high)	20,181	0.02	0.00	0.00	0.00	0.00
57L	Road transport	Combined effect Replace existing pre-Euro VI buses with electric buses (low)	11,253	0.01	0.00	0.00	0.00	0.00
58	Road transport	Road spraying HIGH	915,379			1.12	0.07	
58L	Road transport	Road spraying LOW	71,427			0.47	0.03	
NC	Road transport	Shift of road freight to rail freight	Not costed	0.15		0.09	0.06	0.00
59	Coke production	SCR	4,696	4.80				
60	Coke Oven Gas (COG)	COG Desulphurisation by absorption system (Carl Still, Diamex, ASK or Cyclasulf)	8,261		8.25			
61	Iron & steel - combustion plant	Low-NOx burners with external flue-gas recirculation	934	0.51				
62	Iron & steel - combustion plant	SCR	19,017	3.38				
63	Iron & steel - combustion plant	ESP	8,708			0.02	0.02	
64	Iron & steel - combustion plant	Bag filters	18,113			0.02	0.02	
65	Sinter production	SCR	15,674	9.47				
66	Sinter production	Regenerative activated carbon (RAC)	28,907	5.26	13.94	0.31	0.23	
67	Sinter production	Partial Gas Recycling	8,120	4.21	2.89	0.77	0.58	
68	Sinter production	Bag (fabric or metallic mesh) filter	6,228			1.33	0.99	
69	Sinter production	Bag filter with flow-injection (eg MEROS) to reduce SO2	6,568		8.31	1.37	1.03	

ID	Sector	Measure Description	Total Annualised Cost £kpa	Emission reduction NOx (kt)	Emission reduction SO_2 (kt)	Emission reduction PM10 (kt)	Emission reduction PM2.5 (kt)	Emission reduction VOC (kt)
70	Sinter production	Advanced ESP	2,024			1.37	1.03	
71	Basic oxygen furnaces_Steel production (oxygen converters)	Dry or wet dedusting (ESP or scrubber)	41,497			0.80	0.40	
72	Blast furnaces_Iron production (blast furnace)	Bag filter	13,831			0.26	0.13	
73	Electric arc furnaces_Steel production (electric arc)	Bag filter	531			0.22	0.12	
74	Electric arc furnaces_Steel production (electric arc)	Enclosure	7,192			0.22	0.12	
75	Foundries (Castings)	Enclosure to capture and treat exhaust gas from shake-out	6,875			0.17	0.17	
76	Refineries – combustion (Fuel oil)	Switch to natural gas (no pipeline)	230,485		19.92	0.36	0.24	
78	Refineries – combustion (Fuel oil & OPG)	SCR	16,338	15.84				
79	Refineries – combustion (Petroleum Coke)	SCR	10,675	5.78				
80	Refineries – combustion (All fuels)	SNCR	22,940	11.94				
84	Crude oil loading from onshore facilities	Vapour recovery unit	34,899					9.61
85	Crude oil loading from	Vapour recovery unit	28,116					7.74

ID	Sector	Measure Description	Total Annualised Cost £kpa	Emission reduction NOx (kt)	Emission reduction SO_2 (kt)	Emission reduction PM10 (kt)	Emission reduction PM2.5 (kt)	Emission reduction VOC (kt)
	offshore facilities							
86	Crude oil loading from offshore facilities	Modification to floating production	12,311					6.63
87	Crude oil loading from offshore facilities	Modification to shuttle tankers	13,868					5.48
88	Oil and gas production - gas combustion	Dry Low Nox	831,993	16.06				
89	Oil and gas production - flaring	Improved ignition system on flares	102,433					4.22
90	Other industrial / Public sector / Miscellaneous industrial/commercial combustion	Combustion modification	44,371	22.08				
91	Other industrial / Public sector / Miscellaneous industrial/commercial combustion	Combustion modification + SCR	94,290	41.56				
92	Other industrial / Public sector / Miscellaneous industrial/commercial combustion	Combustion modification + SNCR	25,954	20.78				
93	Other industrial / Public sector combustion (All solid fuels)	Low sulphur coal (0.6%S)	4,553		10.20			
94	Other industrial combustion	Low sulphur oil (0.6%S)	1,634		3.12			

ID	Sector	Measure Description	Total Annualised Cost £kpa	Emission reduction NOx (kt)	Emission reduction SO_2 (kt)	Emission reduction PM10 (kt)	Emission reduction PM2.5 (kt)	Emission reduction VOC (kt)
	(All liquid fuels)							
97	Other industrial / Public sector / Agriculture - stationary combustion (All solid & liquid fuels)	ESP	13,451			6.05	3.44	
98	Other industrial / Public sector / Agriculture - stationary / Miscellaneous industrial/commercial combustion (Natural gas)	ESP (Natural Gas)	1,536			0.69	0.66	
101	Primary aluminium	Inert anodes retrofit	50,197		1.33			
102	Primary aluminium	Wet scrubber	5,703		1.24	0.01	0.01	
103	Animal carcass incineration	Extension of Part B regulation	71,058			0.22	0.22	
104	Glass - container	Ceramic filter	6,465			0.54	0.51	
105	Glass - flat	Ceramic filter	3,674			0.47	0.44	
106	Glass (wool)	Ceramic filter	697			0.06	0.06	
107	Industrial application of adhesives	Substitution	-49					0.55
108	Industrial application of adhesives	Substitution	292					0.54
109	Industrial application of adhesives	Abatement of emissions through incineration	78					8.31

ID	Sector	Measure Description	Total Annualised Cost £kpa	Emission reduction NOx (kt)	Emission reduction SO_2 (kt)	Emission reduction PM10 (kt)	Emission reduction PM2.5 (kt)	Emission reduction VOC (kt)
110	Dry cleaning	New installations - water cleaning	744					1.55
111	Agrochemicals	New product	3					0.19
112	Agrochemicals	Primary and new agrochemical products	71					0.53
113	Domestic products	stage 1 reformulation	12,195					3.11
114	Domestic products	stage 2 reformulation	84,302					17.42
115	Domestic products	stage 3 reformulation	144,517					14.93
116	Organic chemicals	Internal floating covers/sec.seals, vapour recovery (double stage)	16,154					2.64
117	Organic chemicals	Vapour recovery unit (double stage)	7,099					1.24
118	Organic chemicals	LDAR Stage 2	-164					1.94
119	Organic chemicals	LDAR Stage 3	-150					1.94
120	Organic chemicals	LDAR Stage 4	-83					2.53
121	Industrial coatings	Continuous processes - powder coating system	-9,972					5.02
122	Industrial coatings	General industry - powder coating system	-12,916					2.87
123	Industrial coatings	Plastic parts - powder coating system	-29,974					7.16
124	Industrial coatings	High solids coating systems	-890					0.50
125	Industrial coatings	Low solid coating systems	-1,475					0.59
126	Industrial coatings	Very high solid systems	-6,119					3.31

ID	Sector	Measure Description	Total Annualised Cost £kpa	Emission reduction NOx (kt)	Emission reduction SO_2 (kt)	Emission reduction PM10 (kt)	Emission reduction PM2.5 (kt)	Emission reduction VOC (kt)
127	Other food	Schumacher type desolventiser plus old hexane recovery	-3,240					4.94
128	Other food	Schumacher type desolventiser plus new hexane recovery	-4,183					6.40
129	Domestic Combustion	Fuel switching away from coal and oil	435,515	2.88	39.19	7.35	2.76	9.31
130	Domestic Combustion	Homes heated with natural gas swtich to using heat pumps	1,517,444	0.42	-0.24	0.01	0.02	0.13
131	Domestic	Combined effect of cavity wall insulation	455,901	0.70	0.93	0.37	0.20	0.83
132	Domestic	Combined effect of loft insulation	-38,354	0.36	0.47	0.19	0.10	0.45
133	Domestic	Combined effect of solid wall insulation	-1,578,266	4.88	6.46	2.56	1.42	5.75
134	Domestic Combustion	Increased Uptake of A Rated Boilers	29,414	0.24	0.00	0.01	0.01	0.03
135	Domestic	Combined effect of solar water heating	2,563,206	1.48	2.18	0.85	0.47	1.91
136	Electricity generation	Increased Uptake of domestic PV Electricity	2,972,243	1.92	0.90	0.05	0.11	0.05
137	Domestic	Combined effect of district heating	-27,503	8.38	0.41	-0.05	-0.01	0.25
138	Domestic	Combined effect of small CHP/biomass	180,857	0.66	0.15	0.01	0.03	0.10
139	Brick manufacture - Fletton	Dry scrubber	14,174		3.23	0.19	0.12	
140	Railways - intercity, Railways - regional	Electrification	169,298	4.46	0.11	0.11	0.11	0.81
141	Railways - intercity, Railways - regional	Diesel Particulate Filter retrofit	14,828			0.20	0.21	
142	Shipping - coastal	Waste Heat Recovery	-389,580	2.44	0.83	0.11	0.10	

ID	Sector	Measure Description	Total Annualised Cost £kpa	Emission reduction NOx (kt)	Emission reduction SO_2 (kt)	Emission reduction PM10 (kt)	Emission reduction PM2.5 (kt)	Emission reduction VOC (kt)
143	Shipping - coastal	Kites	-56,805		0.79			
144	Shipping - coastal	Fuel switch to LNG	-3,114	11.88	4.87			
145	Shipping - coastal	Charge air humidification (humid air motors, HAM) new	3,242	11.03				
146	Shipping - coastal	Charge air humidification (humid air motors, HAM) retrofit	1,613	6.81				
147	Shipping - coastal	Direct Water Injection (DWI)	4,549	11.85		0.23	0.22	
148	Shipping - coastal	Water diesel emulsion	32,903	2.25		0.18	0.17	
149	Shipping - coastal	Selective Catalytic Recovery (SCR_small)	167,439	21.07				
150	Shipping - coastal	100% Biodiesel or Plant Oil	145,295		1.87	0.09	0.09	
151	Shipping - coastal	DPF	347,603			1.09	1.04	
152	Aviation	Optimise LTO practice* / Derated take-off*	-12,365	0.33				
153	Aviation	Early Aircraft retirement	1,296,219	0.13				
154	Agriculture livestock - broilers	Oil spraying	292			0.40	0.07	
155	Agriculture livestock - other poultry	Oil spraying	11,681			0.96	0.17	
156	Agriculture livestock - pigs	Oil spraying	7,369			0.50	0.09	
157	Agriculture livestock - broilers	Single chemical scrubber	3,695			2.58	0.49	
158	Agriculture livestock - other poultry	Single chemical scrubber	2,296			0.62	0.12	

ID	Sector	Measure Description	Total Annualised Cost £kpa	Emission reduction NOx (kt)	Emission reduction SO_2 (kt)	Emission reduction PM10 (kt)	Emission reduction PM2.5 (kt)	Emission reduction VOC (kt)
159	Agriculture livestock - pigs	Single scrubber	8,985			0.26	0.05	
160	Agriculture livestock - broilers	Two stage scrubber	6,185			2.53	0.49	
161	Agriculture livestock - pigs	Two stage scrubber	12,267			0.25	0.05	
162	Agriculture livestock - pigs	Two step biological scrubber	10,320			0.26	0.05	
163	Agriculture livestock - broilers	Three stage scrubber	5,972			2.67	0.49	
164	Agriculture livestock - pigs	Three stage scrubber	11,846			0.27	0.05	
165	Petrol stations - vehicle refuelling	Vapour balancing system ("Stage II")	31,287					1.58
166	Quarrying	Combined PM control	835			0.66	0.19	
167	Brick manufacture - non Fletton	Combined PM control	276			0.10	0.06	
168	Integrated steelworks - stockpiles	Combined PM control	267			0.21	0.06	
169	Other industry - asphalt manufacture	Combined PM control	85			0.04	0.02	
170	Other industry - part B processes	Combined PM control	611			0.28	0.14	
171	Construction	Combined PM control	30			0.07	0.02	
172	Cement and concrete batching	Combined PM control	91			0.01	0.00	

ID	Sector	Measure Description	Total Annualised Cost £kpa	Emission reduction NOx (kt)	Emission reduction SO_2 (kt)	Emission reduction PM10 (kt)	Emission reduction PM2.5 (kt)	Emission reduction VOC (kt)
173	Other mobile sources	Retrofitting DPFs to >37kW agricultural & industrial off-road machinery (gas oil)	2,257			1.11	0.22	2.60
174	Other mobile sources	Retrofitting DPFs to <37kW industrial off-road machinery (gas oil)	1,192			1.81	1.38	0.56
175	Other mobile sources	Retrofitting SCR to >56kW agricultural & industrial off-road machinery (gas oil)	1,633	11.61				
176	Other mobile sources	Introducing Stage control limits for <19kW for industrial off-road machinery (gas oil)	2,448	3.80		1.02	0.73	0.95
177	Cement	SNCR (Low)	323	0.33				
178	Cement	SNCR (High)	1,150	0.30				
179	Cement	Wet Scrubber	15,510		1.68	0.08	0.04	
180	Cement	Absorbent Addition	791		0.78			
181	Lime	Wet Scrubber	12,321		0.42			
182	Lime	Absorbent Addition	1,053		0.33			
183	Lime	Wet Scrubber	1,080		1.85			
184	Lime	Absorbent Addition	92		1.44			
185	Lime	SNCR (Low)	41	0.06				

4. Uncertainties and Limitations

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 2030 are taken from the NAEI and are governed by uncertainty that is related to the underlying data and assumptions from DECC, BIS, DfT, AEA and other organisations regarding activity levels, BAU uptake of measures, efficiency of measures, etc. The impact of uncertainty in the emission projections has been investigated by AEA[7]. This includes uncertainty in the 2009 base year emissions (see Table 4.1) as well as uncertainty in the activity projections by analysis of a number of different scenarios (see Figure 4.1).

Table 4.1 Uncertainty in 2009 base year emissions (AEA 2012)

Pollutant	Estimated uncertainty
Ammonia	-20% to +20%
Nitrogen Oxides	-10% to +10%
Particulate matter (PM10)	-20% to +30%
Particulate matter (PM2.5)	-20% to +30%
Sulphur dioxide	-4% to +4%
Non methane Volatile Organic Compounds	-10% to +10%

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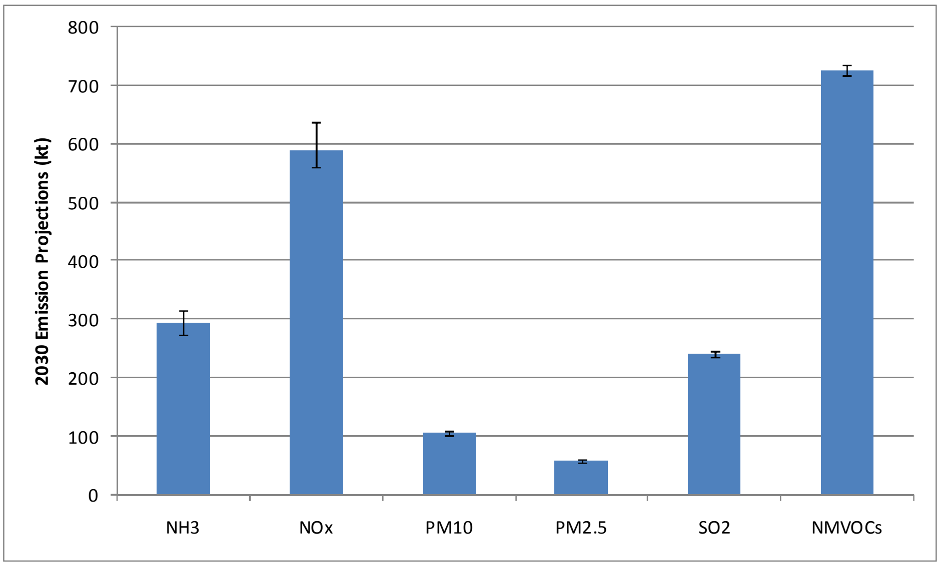
[7] AEA Group (2012): 2012 Air Quality Emission Projections. A report of the National Atmospheric Emissions Inventory, March 2012 [DRAFT].

Figure 4.1 Results from 2030 emissions scenario analysis



Note 1: The error bars represent the scenarios with the lowest and highest emissions estimated. The main bar represents emissions associated with a central scenario, one that has been used to update existing measures and develop new measures for inclusion in the MPMD.

- In addition, in some instances the project team has identified possible issues with the underlying NAEI projections that would benefit from additional review and possible revision. This includes, for example, particulate matter emissions from intensive livestock housing which do not change between 2010 and 2030 (activity or emission factors) despite the fact that a number of farmers will be required to make various improvements to reduce atmospheric emissions under the IPPC (and now Industrial Emissions) Directive. Whilst these improvements will be mainly targeted at reducing ammonia emissions, it does not appear that any knock-on impacts (benefits) are taken into account.

- Linked to the point above, there would be merit in including measures for the reduction of ammonia emissions (developed by another contractor) in the overall MPMD both for consistency and completeness. At present ammonia has only been considered in the MPMD where there are likely to be cross-media impacts from certain abatement techniques targeted at other pollutants.

- Limited information is currently available on the costs and impacts of some measures. Therefore, in some cases it has not been possible to fully quantify the impacts and/or the cost of the measure, although these measures could potentially achieve significant emission reductions (see Appendix A for further details);

- For some sectors (e.g. main VOC emitters), a fairly high level review of possible abatement measures has been undertaken and possible options for abatement (including cost data) are based on measures within IIASA's GAINS model. If these sectors and/or pollutants become a higher priority in the future (e.g. if a tight ceiling is proposed) then it is recommended that further work is undertaken to ensure any measures included in subsequent scenario analysis (and associated costs and emissions impacts) are suitable for UK sectors;

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

- The uptake of an abatement measure within a sector is subject to uncertainty due to variations across the sector in size/site specific factors and/or lack of information on what is assumed under BAU (e.g. existing technology in place) and how some sectors may respond to current legislation. For each sector the potential uptake of measures has been determined based on published information available and/or consultation with sector experts. For some sectors various uptakes have been considered. It should be noted that the interpretation of the potential uptake of measures varies from sector to sector, for instance it may be derived based on emission projections, activity information, or volumes of product produced (see Appendices for further details);

- Implementation costs of abatement measures will vary within a sector due to variations across the sector in; size/site specific factors (for instance of a plant), existing technology in place and the potential lifetime of the measure. When available, ranges of cost estimates for the measures considered have been presented in the Appendices to indicate the variability/uncertainty of the estimates.

Appendix A
Sector Analysis

A1. Contents

A1. Domestic Energy

A1.1 Sector profile

Table A1.1 and Table A1.2 present the 2025 and 2030 emissions for the residential sector developed by AEA, based on DECC's UEP43 forecasts and the 2009 baseline National Atmospheric Emission Inventory (NAEI).

Table A1.1 Emissions for domestic sector for 2025[1]

SnapID	Source Name	Activity Name	Emissions (kt)				
			NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC
202	Domestic Combustion	Anthracite	0.74	3.30	0.06	0.25	0.36
202	Domestic Combustion	Burning Oil	1.95	0.31	0.06	0.08	0.03
202	Domestic Combustion	Coal	1.09	10.82	2.00	5.26	6.54
202	Domestic Combustion	Coke	0.00	0.00	0.00	0.00	0.00
202	Domestic Combustion	Fuel Oil	0.00	0.00	0.00	0.00	0.00
202	Domestic Combustion	Gas Oil	N/S	N/S	N/S	N/S	N/S
202	Domestic Combustion	LPG	0.28	0.00	0.01	0.01	0.02
202	Domestic Combustion	Natural Gas	22.34	0.00	0.57	0.57	2.55
202	Domestic Combustion	Peat	0.02	0.00	0.10	0.28	0.83
202	Domestic Combustion	Petroleum Coke	0.48	17.25	0.14	0.37	0.59
202	Domestic Combustion	SSF	0.90	4.75	0.24	0.90	1.45
202	Domestic Combustion	Town Gas	N/S	N/S	N/S	N/S	N/S
202	Domestic Combustion	Wood	0.79	0.12	6.34	8.93	26.70

Note: data on gas oil emission was not included in the NAEI data. N/S denotes 'not stated'.

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[1] Note that there are also considerable indirect emissions (i.e. emissions from power stations) associated with the use of electricity in the domestic sector. Some of the measures evaluated in this sector have cross-sectoral impacts such as insulation measures which reduce electricity used for heating and measures which generate electricity (microgeneration or CHP).

Table A1.2 Emissions for domestic sector for 2030

SnapID	Source Name	Activity Name	Emissions (kt)				
			NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC
202	Domestic Combustion	Anthracite	0.92	4.11	0.07	0.30	0.45
202	Domestic Combustion	Burning Oil	1.62	0.26	0.05	0.06	0.02
202	Domestic Combustion	Coal	1.36	13.51	2.47	6.57	8.16
202	Domestic Combustion	Coke	0.00	0.00	0.00	0.00	0.00
202	Domestic Combustion	Fuel Oil	0.00	0.00	0.00	0.00	0.00
202	Domestic Combustion	Gas Oil	N/S	N/S	N/S	N/S	N/S
202	Domestic Combustion	LPG	0.23	N/S	0.01	0.01	0.014
202	Domestic Combustion	Natural Gas	23.55	N/S	0.60	0.60	2.69
202	Domestic Combustion	Peat	0.02	N/S	0.10	0.27	0.82
202	Domestic Combustion	Petroleum Coke	0.59	21.5	0.17	0.46	0.74
202	Domestic Combustion	SSF	1.12	5.92	0.29	1.12	1.81
202	Domestic Combustion	Town Gas	0.00	0.00	0.00	0.00	0.00
202	Domestic Combustion	Wood	0.78	0.12	6.33	8.92	26.7

Note: data on gas oil emission was not included in the NAEI data. N/S denotes 'not stated'.

There are a considerable number of existing policies in the domestic sector focused on reducing energy consumption by improving energy efficiency and switching to cleaner burning fuels. Both of these techniques are aimed at reducing emissions of CO_2 but also have the effect of reducing emissions of air pollutants.

The historical impact of such policies can be seen by considering the energy consumption in the UK domestic sector. The BRE Domestic Energy Fact File (hereafter referred to as the "Fact File") contains detailed data on energy consumption up to 2001. It shows that domestic sector energy consumption rose by 31.5% between 1970 and 2001. In the same period, the number of dwellings rose by 35.8%, meaning that the average energy consumption per dwelling has actually fallen slightly (even after taking into account rising external temperatures)[2].

The general approach adopted in this report to estimating the improvement potential is to consider the anticipated take-up of certain measures in 2025/2030 (BAU baseline) and then to consider how this could be improved to a maximum potential take-up for a given measure (BBAU potential).

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[2] BRE, Domestic Energy Fact File, 2003. Later versions of the BRE Domestic Energy Fictile have been referred to later in this document to update the information and are referenced accordingly.

DECC publishes Updated Energy and Carbon Emissions Projections (UEP) reports which are used as the basis of the NAEI data. The NAEI data is based on UEP reports, so the BAU baseline for take-up of certain measures is assessed to correspond with whichever UEP policy scenario has been used in the latest NAEI reports.

It is clear from the UEP and NAEI reports which policies have been factored in to projections[3]. However, only the high level CO_2 emissions savings from each policy are given. There is no information on what the underlying assumptions are for changes in the residential sector that will generate these emissions, but clearly the policies implemented will have an impact on the BAU take up of measures being considered in this report. The key policy changes since the UEP43 projections were developed, which will impact on take-up of these (and other) energy saving measures are summarised in Table A1.3 below.

Table A1.3 Key policies considered unlikely to be included in 2010 predictions

Policy	Impacts	Included in UEP/NAEI	Estimated impact in 2025 / 2030 $MtCO_2$
Renewable Heat Incentive (RHI)	To drive a step change on the uptake of renewable heat technologies to help deliver increase in renewable heat from current 1.5% of total heat demand to some 12% by 2020. This will be achieved by creating a subsidy framework for the various technologies. It consists of tariffs paid to companies who add to renewable heat generation. The Coalition Government have decided to delay implementation to 2012 in order to consider cost effective way to support increased uptake.	N	A reduction of 31 (Traded) and 211 (Non traded).
Energy Act 2011 (Green Deal Elements of the Energy and Climate change Bill)	To improve the energy efficiency of the existing UK building stock, including households and non domestic properties, to cost effectively reduce GHGs as part of the UK's long term commitment to achieving a 34% reduction in C02 emissions (relative to 1990 levels) and an 80% reduction by 2050.	N	Not stated.

Estimated Impacts derived from relevant Impact Assessment i) RHI: IA DECC 0057 01/12/2011. ii) DECC Energy Act 2011: Green Deal Impact assessment.

A1.2 Impact on BAU take up of insulation and boilers

Where evidence has been available on the current/forecast installation numbers from policy documents, their associated impact assessment or other publicly available data, we have referred to these in establishing BAU take up rates. The approach and rationale for each measure is explained further below.

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[3] Generally speaking the predictions include what are referred to as 'firm and funded' policies. Those which were passed into legislation before summer (August) 2010, we have assumed have been incorporated into the projections.

Where data was not available AMEC have taken figures from the most recent BRE Fact File document (2008) as the basis for estimating penetration of energy efficiency measures. This document presented various historical trends (going back to 1991) which have been used as the basis for predicting take up. The approach and data sources taken for specific measures are explained further in the relevant sections below.

A1.3 BAU take up of micro-renewables

There is reasonable data on the current level of deployment of renewable technology in the UK. According to a BERR report[4], there were 1,301 PV installations and 78,470 solar water systems in the UK in 2008. It is assumed that the majority of these are domestic installations. In estimating future take-up of renewable based on existing policies, AMEC have considered the policies included within the UEP 43 projections, as follows:

Table A1.4 Take up of micro-renewables – policies considered in UEP 43 projections

Policy
Building Regulations Part L (2002 & 2005/6)
Warm Front & Fuel Poverty Measures
Supplier Obligation (prior to LCTP)
Supplier Obligation (in LCTP)
Building Regulations 2010 Part
Smart Metering
EU Products policy (Tranche 1, Legislated)
EU Products policy (Tranche 2, Proposed)
Community Energy Saving Programme
Zero Carbon Homes
ECO and Domestic Green Deal
Renewable Heat Incentive

Source: AEA UEP43 Projection Report. Draft UK Air Quality Emissions Projections 2005-2030.

A1.4 Other impacts of BAU policies

The analysis above considers the impacts of existing policies on take up of certain types of insulation, fuel switching and installation of replacement boilers and microrenewables. It is also likely that the policies will begin

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[4] BERR – The current status and prospects for microgeneration technologies (2008 data levels)

to influence other areas considered in detail in this report. For example, the supplier obligation is expected to shift the focus of supplier investment in energy efficiency away from loft and cavity wall insulation and towards higher cost measures such as solid wall insulation, CHP and district heating. In addition, the assessment of some of the measures is complicated by cross-sectoral impacts (e.g. implementation of CHP and district heating affects both residential and power generation sectors).

In the longer term, there are expected to be significant changes in the type of domestic heating system used in the UK with significant increases for district heating and alternative fuels such as biomass. There is scope to consider the impact of improving the efficiency of such systems. However, given that current energy predictions from NAEI appear to only include minimal take-up of biomass to 2020 (some further growth is anticipated after that, although the amount was not quantified in the NAEI report) and district heating, the options for abatement by applying further measures to biomass boilers/district heating with other fuels has not been considered in detail at this stage.

A1.5 Beyond business as usual

Much of the BAU impacts on emissions in the domestic sector are driven by policy initiatives intended to reduce GHG emissions. This is a rapidly developing policy arena and there are a large number of policies yet to be included in DECC’s underlying energy projections. These policies are intended to stimulate major changes in domestic energy use, as noted above. Our assumptions for each beyond business as usual (BBAU) scenario are detailed under the relevant measures, in the sections that follow.

1.5.1 Methodology/assumptions

Overall methodology

The central task to estimate the take up and impact of abatement measures is to forecast housing numbers to 2025 and to 2030. These estimates have been based on the most recent BRE Fact File (2008). This source has also been used to estimate historical market penetration of various technologies, such as cavity wall insulation and space heating per household.

In the 2008 BREF Fact File report, the number of households in the UK is detailed until 2006, at which point the estimate was 25,285,000. This number is then extrapolated based on historical trends. Between 1991 and 2006 some 185,000 dwellings were constructed per year. This annual growth rate is then is used to project the number of dwellings in the UK in 2025 and in 2030. This is a simplified methodology which attempts to estimate in very broad terms the overall number of homes over the longer term. It presupposes that housing slow-down brought about by the recessions in both 2009 and 2012, will be offset over the longer term by a recovery in the economy, alongside Coalition Government policies[5] designed to boost the overall quantum of house building. The market penetration predictions are then applied to these totals in order to determine the BAU market penetration of various abatement measures. Details regarding the BAU penetration assumptions and calculations of each measure are explained below.

Abatement measure 1: Fuel switching

As coal and oil are fuels which result in high emissions for the pollutants covered in this assessment, a beyond BAU abatement technique for the domestic sector that has been considered is the replacement of all coal (including anthracite, coke and petroleum coke) and 50% of oil with natural gas and electricity. The assumption is that 50% of the replacement is to gas but the remaining 50% is switched to electricity on the basis that it is likely to remain off the gas network.

An additional measure has also been included (Measure 1a) that assumes 6% of homes heated with natural gas switch to using electricity (heat pumps) by 2030.

Business as usual assumptions

The impact of this measure is calculated according to UEP43 predictions for energy consumption by different fuels in the sector. Therefore the BAU case is the amount of energy consumed/delivered by each fuel type in the UEP43 projections.

Beyond business as usual assumptions

It is assumed that, by 2025, there will be no homes heated by coal boilers (including anthracite, coke, and petroleum coke). Furthermore, it is assumed that oil consumption in the domestic sector will also drop by 50%. The former coal and oil consumption will be replaced by a mix of natural gas (50%) and electric heat-pumps (50%).

Methodology and assumptions

To calculate the increase in emissions arising from the electricity generation industry due to an increase in electricity consumption required to run heat pumps, emissions factors have been calculated utilising the NAEI projected pollutant emissions due to combustion for electricity production divided by total electricity demand projections from UEP43. These projections are detailed in table A4.5 below.

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[5] An example of such a policy is the National Planning Policy Framework. This contains a stronger presumption in favour of sustainable development than hitherto.

Table A1.5 Electricity emissions projections

Year	Electricity Demand		Emissions Projections (kt)					Emissions Factor (g/GJ)				
	billion kWh	GJ	SO_2	NO_x	$PM_{2.5}$	PM_{10}	VOC	SO_2	NO_x	$PM_{2.5}$	PM_{10}	VOC
2025	341	1,228,111,200	31.05	93.87	1.75	2.40	2.30	25.3	76.4	1.4	2.0	1.9
2030	367	1,322,071,200	17.64	71.63	1.47	1.98	1.94	13.3	54.2	1.1	1.5	1.5

The amount of energy projected to be used in each dwelling, for space heating purposes, was projected using the Fact File information which states that in 2006, 42.2 GJ (delivered energy) per year are used per dwelling for space heating. An average improvement of heat loss per dwelling is assumed to be 1% per year. This leads to an estimation of 35 GJ/dwelling in 2025 and 33 GJ/dwelling in 2030.

The capital costs of this measure were calculated by determining the costs of installation of a gas central heating system (in 2011 prices), as well as a ground or air-source pump heating system, and applying these costs to the number of dwellings that will be affected. The number of affected dwellings was calculated by determining the number of GJ to be switched from coal to gas, coal to electricity, oil to gas and oil to electricity, and then dividing these numbers by the estimated number of GJ consumed per dwelling. This is summarised in the tables that follow and in A4.22 at the end of this section of the report.

Table A1.6 Capital costs of fuel switching

	Cost per house (£)		
	Low	High	Avg
Gas boiler	3,832	3,832	3,832
Electric heat pump	6,570	13,140	9,855

Table A1.7 Uptake of fuel switching

Switch	Number of houses	
	2025	**2030**
Coal to Gas	364,423	478,441
Coal to Electricity	364,423	478,441
Oil to Gas	197,552	173,677
Oil to Electricity	197,552	173,677
Total	**1,123,951**	**1,304,237**

All prices are presented in 2011 prices. Fuel prices were calculated using the 1996 base price for the various fuel types, taken from the 2008 Fact File, and converted in 2011 prices using the retail price index (fuel components) relative to GDP deflator[6] as shown below.

Table A1.8 Fuel prices

Fuel	2011 Price (£/GJ)	2011 Price (p/kWh)
Coal	9.84	27.34
Oil	8.54	23.74
Gas	9.61	26.70
Electricity	43.26	120.19

Operating costs are a combination of the price difference between the fuels that were being switched and maintenance costs, as detailed in the table below. Fuel consumption for each heating system is based on a range of efficiencies given for different heating systems in Standard Assessment Procedure (SAP)[7].

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[6] DECC, Quarterly Energy Prices, December 2008 (http://www.berr.gov.uk/files/file49203.pdf)

[7] The following efficiencies/coefficients of performance are used: average heating system 78%; oil 75%; coal 65%; gas 80%; electricity (conventional) 100%. Heat pumps are assumed to have a 400% efficiency (Source RHI Impact Assessment, P35).

Table A1.9 Operating costs of fuel switching for 2025 and 2030

Fuel switch	Change in annual fuel bill per home (£)	
	2025	2030
Coal to Gas	-85.9	-81.71
Coal to Electricity	-138.82	-132.99
Oil to Gas	16.9	16.09
Oil to Electricity	-35.9	-35.19

Abatement Measure 1a: Homes heated with natural gas switch to using heat pumps

Business as usual assumptions

As above, the impact of this measure is calculated according to UEP43 predictions for energy consumption by different fuels in the sector. Therefore the BAU case is the amount of energy consumed/delivered by each fuel type in the UEP43 projections.

Beyond business as usual assumptions

This measure assumes further evolution of Measure 1 noted above. In this case homes that would be heated with natural gas instead use heat pumps with a 400% rate of efficiency[8]. We assume that this switch occurs in 50% of the new homes constructed between 2011 and 2025/2030.

Methodology and other assumptions

Estimates published by DECC in 2011[9], suggest 0.9% of the housing stock had GSHP installed in 2011. We have assumed that some 50% of the newly constructed housing stock between 2011 and 2025/2030 has ground source heat pumps installed (i.e. some 1.3 million by 2025 and some 1.8 million by 2030). We base the housing projections on a continuation of housing numbers set out in the Factfile 2008, as explained under Measure 1 above.

The scale of and costs for the implementation of this measure are summarised in the table below and in the overall summary in section A4.6.

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[8] Source Department of Energy and Climate Change (DECC) 2011, Renewable Heat Incentive (RHI) Impact Assessment, P35.

[9] Department of Energy and Climate Change (DECC) 2011, UK Renewable Energy Roadmap http://www.decc.gov.uk/assets/decc/11/meeting-energy-demand/renewable-energy/2167-uk-renewable-energy-roadmap.pdf Page 89. Accessed 24th July 2012

Table A1.10 Cost scenarios for Measure 1a – Homes heated with natural gas switch to using heat pumps

	2025	2030
Number of Affected Households	1,295,000	1,757,500
Cost of GSHP Installation (£)[10]	13,000	13,000

Abatement Measure 2: Increased uptake of cavity wall insulation

Business as usual assumptions

Historic trend data in the Fact File, alongside increasingly stringent building regulations suggest the proportion of dwellings with cavity wall insulation will continue to rise under BAU. All new builds will employ this technology, and many existing dwellings will be retro-fitted. Reflecting the age of the fact file data (2006), we also reviewed more recent DECC data (2012) on home insulation levels, data, suggesting market penetration as of 2012 of some 59% of the housing stock with potential for such insulation[11]. Reflecting the trends noted above, we have increased uptake by 2025 and 2030 by a further 29%, which suggests that some 19.3 million homes could have cavity wall insulation by 2030. This equates to some 88% of the housing stock with potential for cavity wall insulation; some 67% of the total housing stock. This is the BAU uptake rate we have used.

BAU energy use in the domestic sector is deduced from NAEI total emissions and emissions factors for the majority of fuels, however, this gives no energy use for electricity in the domestic sector (all of the emissions from electricity generation are assigned to the electricity sector in NAEI figures). There is considerable use of electricity for space heating within the domestic sector and measures to reduce the demand for space heating will have knock on effects in the electricity generation sector. Therefore, the energy use for electric space heating has been estimated based on BRE factfile figures for the proportion of homes using electric space heating. This suggests ~9% use central electric systems and ~3% use non-central electric heating. The Fact File also suggests that the total proportion of homes using electric space heating has been consistent at ~12% for some time. This suggests BAU will lead to ~3.5m homes having electric heating in 2025 and ~3.6m in 2030. The average energy use per home has then been calculated as per the calculation for fuel switching (above) to determine the energy use for electric space heating.

Beyond business as usual assumptions

This measure calculates the effects of increasing the uptake of cavity wall insulation to a rate such that all possible homes will have cavity wall insulation by either 2025 or 2030. The measure will also reduce electricity

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[10] Estimated capital installation costs - Energy Savings Trust http://www.energysavingtrust.org.uk/Generate-your-own-energy/Ground-source-heat-pumps

[11] Department of Energy and Climate Change (DECC). January 2012.Estimates of Home Insulation levels in GB.

consumption for space heating. Therefore the impact on the electricity generating sector has also been calculated and is explained below.

The BBAU scenario we have used is that all homes with the potential for Cavity wall insulation has this installed. This is based on projecting forward trends in the 2008 BRE Fact File data. This states that, as of 2006, approximately 18.5 million homes could potentially have cavity wall insulation. It was then assumed that all homes built after this time will also have this type of insulation. Using the projection for total number of dwellings to be constructed between now and 2030 discussed in the overall methodology above, it is predicted that, by 2030, 22.94 million homes could potentially have cavity wall insulation, some 77% of the total estimated housing stock.

Methodology and other assumptions

Ofgem has published an *Energy Efficiency Commitment, 2005-2008, Technical Guidance Manual* as well as an accompanying scheme spreadsheet. This spreadsheet details the energy savings of various housing types if cavity wall insulation is installed. AMEC have used a 3 bedroom semi-detached house as being representative of the housing stock. The increased uptake of installing cavity wall insulation in this house type translates to energy savings of 5% across the sector (in 2025). This savings is applied equally to each fuel type from the NAEI projections as well as the estimated consumption for electric space heating to determine the net decrease of each air pollutant. Emissions reductions have been calculated separately for direct and indirect emissions (see summary tables in section A1.6). However, costs have not been disaggregated between electrically heated homes and homes heated by combustion systems. The numbers of affected homes are shown below.

Table A1.11 Measure 2 – All Potential Homes have Cavity Wall Insulation by 2025 and 2030

	2025	2030
Number of Affected Households	4,183,040	1,605,870
Cost of Cavity Insulation Installation per house (£)[12]	1,050	1,050

Abatement Measure 3: Increased uptake of loft insulation

Business as usual assumptions

The Fact File predicted in 2003 that by 2020 approximately 60% of homes would have at least 100 mm of loft insulation. Analysis of the impact of the firm and funded policies introduced since 2003 and included in UEP43 suggests that current BAU anticipates this to rise to 89% of homes having at least 100mm of loft insulation. Saturation is 90% as not all homes have lofts that could be insulated.

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[12] Department of Energy and Climate Change (DECC) Green Deal Impact Assessment, 2011, Page 118.

Beyond business as usual assumptions

This measure determines the effects of increasing uptake of loft insulation, in two scenarios:

i. Dwellings that do not have at least 100 mm currently installed. It therefore assesses the effects of 1% of dwellings installing improved loft insulation from approximately 50 mm to 270 mm.

ii. Dwellings that have >100mm but less than 270mm currently installed. There are no statistics available on the breakdown of homes with insulation >100mm, but it has been assumed that 25% of homes could have lofts insulated from 150mm to 270mm.

Topping up thicker insulation is considered to have diminishing returns and has not been considered.

Methodology and other assumptions

Based on the projected number of dwellings to exist in 2030, the combined effects of both BBAU scenarios noted above, would result in a further 7.5 million homes topping up their loft insulation by 2030.

The Ofgem *Energy Efficiency Commitment* spreadsheet details the energy savings of various housing types, if they top up their loft insulation from 100mm to 270 mm. AMEC have used a 3 bedroom semi-detached house as being representative of the housing stock. Topping up loft insulation from 100 – 270 mm in this house type translates to energy savings of around 1,000kWh per home.

No figure is available in the spreadsheet for top up from 150mm to 270mm, however, interpolating from the 5 data points in the spreadsheet suggests this will save around 500kWh per home.

The combined energy saving from a relatively small number of homes going from 100mm to 270mm and a larger number going from 150mm to 270mm amounts to 1% reduction across the sector by 2025 and a similar proportion by 2030.

This saving is applied equally to each fuel type from the NAEI projections as well as the estimated consumption for electric space heating to determine the net decrease of each air pollutant. As with loft insulation, emissions reductions have been calculated separately for direct and indirect emissions (see summary tables in section A1.6). However, costs have not been disaggregated between electrically heated homes and homes heated by combustion systems. The costs for the implementation of both elements of this measure are summarised in the table below.

Table A1.12 Measure 3 – All lofts with <100 mm of Insulation are topped up to 270mm and 25% of lofts >100mm topped up from 150mm to 270mm

	2025	2030
Number of Affected Households (100mm to 270mm/150mm to 270mm)	2,88,000 / 7,200,000	297,250 / 7,431,250
Cost of Topping Up Loft Installation (£)[12]	216	216

Abatement Measure 4: Solid wall insulation

Solid wall insulation can be applied either internally or externally to homes without cavity wall construction. Mass uptake of this measure is encouraged so the potential impact of applying this measure to all solid wall homes has been assessed. This measure will also impact on indirect emissions as electricity use for space heating is reduced.

Business as usual assumptions

Measure 2 examines uptake of cavity wall insulation 2025 and 2030. The remaining homes (estimated at some 6.7 million) will have a solid wall construction meaning it is more difficult and more expensive to insulate.

Currently virtually no solid wall properties have had insulation retro-fitted; however, the expectation is that the Supplier Obligation (which will run until December 2012, and thereafter policies set out in the Green Deal) will result in further uptake of solid wall insulation (either internal or external insulation).

The Partial Regulatory Impact Assessment accompanying the Community Energy Saving Programme (CESP) consultation indicates that for terraced homes typical savings are ~1.5ktCO2 pa (8,000kWh pa in a gas heated home) and that costs are around £3k - £4.5k. Assuming these costs and benefits rise by 50% for a typical home (based on a gas heated semi-detached house), 3.3MtCO2 amounts to around 1.5m homes having solid wall insulation by 2020. This has been revised upwards so that by 2025 and 2030 some 2.2 million homes, of the c. 6.7 million with potential for installation will have solid wall insulation.

Beyond business as usual assumptions

The maximum potential take-up is assumed to be all homes that do not have cavity walls.

Methodology and other assumptions

There is only limited information available on the cost and benefit of solid wall insulation. AMEC have drawn on the Green Deal Impact Assessment[13] and professional judgement to estimate the costs and benefits of insulating an

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[13] Department of Energy and Climate Change (DECC) Green Deal Impact Assessment, 2011, Page 118.

average solid walled home (solid walled properties tend to be pre-war and are expected to include large numbers of rural homes as well as urban terraced properties).

The energy saving from solid wall insulation amounts to a 14% reduction across the sector (in 2030).

This saving is applied equally to each fuel type from the NAEI projections as well as the estimated consumption for electric space heating to determine the net decrease of each air pollutant.

As with loft and cavity wall insulation, emissions reductions have been calculated separately for direct and indirect emissions (see summary tables in section A1.6). However, costs have not been disaggregated between electrically heated homes and homes heated by combustion systems. The number of affected homes are shown below.

Table A1.13 Measure 4 – All solid walls are insulated

	2025	2030
Number of Affected Households	4,584,000	4,584,000
Cost of solid wall insulation (£)	4,705	4,705

Abatement Measure 5: Increased uptake of A rated boilers

Current regulations state that, where technically feasible, boilers must be replaced with SEBDUK A or B rated boilers. The beyond BAU scenario being considered is that all boilers that are replaced must be replaced with SEBDUK A rated boilers only.

Business as usual assumptions

The Fact File (2003) depicts various scenarios developed under the Market Transformation Programme for the take-up of condensing boilers. Business as usual is assumed to be equivalent to scenario P1' considered in fact file data, which assumed market saturation of condensing boilers of 78% by 2020, and we have applied the same saturation point for 2025 and 2030 respectively. These saturations are a percentage of potential; it is therefore assumed that the saturation percentages are of those homes being heated with gas and oil only.

Furthermore, it is also assumed that policies not included in the Fact File scenarios lead to a further take-up of A-rated boilers. For 2025 BAU uptake, the take-up of A-rated boilers is increased by 6 million on top of the BRE prediction, and the 2030 take-up of A-rated boilers is increased by 8.3 million on top of the BRE prediction.

For the purposes of this study, it is assumed that, under the BAU scenario, 25%[14] of natural gas and oil boilers are replaced with A-Rated boilers with an efficiency rating of 91%, and the remainder are replaced with B-Rated boilers with an efficiency rating of 88%[15].

Beyond business as usual assumptions

The beyond business as usual case in this measure is that all of the natural gas and oil boilers that are replaced are only replaced by A-Rated boilers, with an efficiency of 91%. While the design of more thermally efficient boilers does not necessarily equate to lower NOx emissions, it is assumed that the small increase in efficiency will mean NOx emissions per kWh fuel input will be similar for both boilers and so reductions arise as more efficient boilers require lower fuel input as they can be smaller or operated less to still meet the heat demand.

Methodology and other assumptions

The approach taken to calculating emissions benefits is to calculate the number of boilers improved from B- to A-rated boilers. This is based on the number of homes using gas or oil as a fuel (determined using the portion of energy use represented by gas and oil in the NAEI projections) multiplied by BAU take-ups estimated from the Fact File (2003) and simplified estimation of further take-up, noted above. Each home is then assumed to use a certain amount of energy for space and water heating (again the amount is determined from the Fact File). This predicts a constant 18.9GJ per household for hot water, space heating energy use is also discussed in Measure 1 above).

The benefit is then calculated by considering the reduction in energy use from a 91% efficient boiler compared to an 88% efficient boiler. The anticipated effects by 2025 and 2030 are shown below.

Table A1.14 Calculations for Measure 5

Year	Number of boilers improved	Energy use per home for space heating and hot water (GJ)[16]	Total energy use (GJ)	Change in efficiency (%)	Energy Reduction (GJ)
2025	2,310,327	54.1	**486,690,877**	**3**	**14,600,726**
2030	7,466,512	52.3	**391,174,492**	**3**	**11,735,235**

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[14] Minimum efficiencies in Part L 2006 require replacement domestic gas and oil boilers to be at least B-rated (except in special circumstances). Solid fuel boilers and some other heating appliances (e.g. cooking ranges) have lower efficiency standards. AMEC have been unable to obtain sales information for A- and B-rated boilers, however, as A-rated boilers are typically more expensive, it is assumed that B-rated boilers will dominate.

[15] SEDBUK ratings are based on the seasonal performance of boilers (i.e. the average efficiency over the course of the year). Bands are as follows; B-rated 86-90%, A rated >90% www.sedbuk.com/pages/bands.htm

[16] Note this includes space heating and hot water (both of which are usually supplied by boilers) whereas previous figures for energy consumption affected by different types of insulation have been for space heating only

This energy that is no longer needed across the sector as a result of this measure equates to an overall reduction of 0.3% in the year 2025 and 0.95% by the year 2030. This percentage is applied evenly to gas and oil fuels in order to determine the reduction in air pollutants resulting from this measure.

It is assumed that the cost difference between installing a B-Rated boiler and installing an A-Rated boiler is an average of some £220[17]. Operating costs are based on the weighted averages of the fuel types used in the sector (from the central projections show in table A4.1 at the beginning of this chapter), and the savings in each fuel type as calculated using the retail price index (fuel components) as detailed in Table A1.8 above. There are no maintenance costs in the calculations as it is assumed these would be the same with either type of boilers and hence be unaffected.

Table A1.15 Calculations of operating costs

Fuel	Amount of Fuel Saved (GJ) (2025)	Fuel Cost (£million) (2025)	Amount of Fuel Saved (GJ) (2030)	Fuel Cost (£million) (2030)
Natural Gas	14,255,365	137.0	11,514,074	110.6
Burning Oil	345,361	2.952	221,161	1.890
Gas Oil	0	0	0	0
Total	14,600,726	139.9	11,735,235	-112.5

Rounding on each row means that totals may not correspond to the sum of rows above

Abatement Measure 6: Solar water heating

Solar water heating systems use heat from the sun to work alongside conventional water heaters. The technology is well developed with a large choice of equipment to suit many applications. Solar water heating can provide approximately a third of the domestic hot water needs of a typical household. Current BAU uptake of such systems has been estimated by taking annual average installation rates alongside making additional allowance for the impact of the Renewable Heat Incentive[18] (RHI) and projecting these trends to 2025 and 2030.

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[17] This costs has been updated from 2008 prices (£200) to 2011 prices and is approximate.

[18] Department of Energy and Climate Change (DECC) Renewable Heat Incentive (RHI), 2011 Impact Assessment (Page 12-14) assumes "some, limited uptake'. On this basis an additional 2.5% has been assumed.

Business as usual assumptions

Based on a continuation of historical trends, alongside an allowance for ‘some limited uptake’ as a result of the Renewable Heat Incentive[19] noted earlier, the BAU take-up of solar water heating is some 161,000 (0.6% of the housing stock) by the year 2025, and some 167,000 (also 0.6%) by 2030.

Beyond business as usual assumptions

Solar water heating can be used in the home, or for larger applications such as pools. The major issue with its implementation is space and exposure (approximately 3-4 square meters of southeast to southwest facing roof receiving direct sunlight for the main part of the day is required). It is therefore assumed that the maximum possible uptake of this measure is 30% of households in the UK (in both 2025 and 2030). This is because of the orientation of the housing stock, as well as the distribution – some 25% are flats where it is more challenge to incorporate into the design because of the lower ratio of roof area to number of dwellings or retro-fit.

Methodology and other Assumptions

Energy savings resulting from this measure were calculated by converting Energy Savings Trust CO_2 savings information into energy savings. The ratio of different heating systems is taken from the NAEI projections taking into account the estimated use of electricity for space and water heating in the UK (see Abatement Measure 2 for more details). These numbers were applied to the total affected households in order to determine fuel savings for each fuel type. These savings were then applied to the cost of fuel as calculated in previous measures in order to determine fuel cost savings. According to Renewables Advisory Board (RAB), solar thermal systems cost approximately £50/year to maintain[20]. This cost was applied to each house implementing the system, as shown below.

Air pollutant reductions are calculated by subtracting the amount of each fuel saved from the BAU projection of each fuel’s consumption and multiplying the new consumption by each emission factor.

As with loft and cavity wall insulation, emissions reductions have been calculated separately for direct and indirect emissions (see summary tables at the end of this section). However, costs have not been disaggregated between electrically powered water systems and water systems fuelled by combustion systems.

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[19] Department of Energy and Climate Change (DECC) Renewable Heat Incentive (RHI), 2011 Impact Assessment RHI Impact Assessment (Page 12-14).

[20] £45.75 in 2008 prices. updated to 2011 prices (£50).

Abatement Measure 7 - Solar Photovoltaic (PV) Electricity

Solar photovoltaic electricity

Solar photovoltaic (PV) systems use energy from the sun to produce electricity which can be used in the home. The amount of electricity provided depends on the size of the system, or the number of panels involved. Current BAU uptake of these systems assumes that previous rates of growth are not sustained, reflecting changes to the Feed in Tariff (FIT) and assumes take up of around 10% by 2025. The beyond BAU scenario being considered is that all potential homes (30% of the total stock) have this technology installed by 2025.

This measure will also impact on indirect emissions only as the need for electricity generation is reduced.

Business as usual assumptions

Based on the DECC Feed in Tariffs data[21], we estimate a BAU take-up of 2,725,000 (9.46%) dwellings by 2025, and 2,945,000 (9.91%) by 2030.

Beyond business as usual assumptions

The major consideration with the implementation of PV is space and exposure. A 1kW peak system requires approximately 8-10 square meters of southeast to southwest facing roof receiving direct sunlight for the main part of the day to function. It is therefore assumed that the maximum possible uptake of this measure is 30% of households in the UK (in both 2025 and 2030). This is because of the orientation of the housing stock, as well as the distribution of housing types – 25% are flats which are difficult to either retro-fit or include in initial designs due to the lower ratio of roof area to number of dwellings.

Methodology and other assumptions

A 1 kW peak system will produce around 2.9 GJ of electricity per year. If applied to all feasible properties, this equates to a saving of 1.4% of project electricity consumption in 2025 and a 1.3% saving in 2030. These savings are then applied to the projected pollution levels resulting from electricity production in order to determine pollutant reductions due to the measure.

The projected cost of electricity is used to determine fuel savings costs, and maintenance costs of £125/house/year are assumed[22]. Cost information for 2025 and 2030 is summarised in the following tables and in more detail in section A4.6.

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[21] Department of Energy and Climate Change (DECC) Feed In Tariff (FIT) - Consultation of Comprehensive Review Phase - tariffs for solar PV. Figure 4 page 16. We have assumed that due to FIT changes, the 2011 rate of growth will not be sustained and assumed some 25,00 installation in 2010, increasing to 100,000 to 2015; 220,000 per year thereafter to 2030.

[22] Renewables Advisory Board, The Role of Onsite Energy Generation in Delivering Zero Carbon Homes, 2007. The original (2008) figure of £114 has been updated to 2011 prices.

Table A1.16 Overall cost scenarios for Measure 7

	2025			2030		
	Low cost	High cost	Average cost	Low cost	High cost	Average cost
Capital Cost per House (£)	5,474	10,949	8,212	5,474	10,949	8,212
Affected Houses in BAU	2,725,000	2,725,000	2,725,000	2,945,000	2,945,000	2,945,000
Affected Houses with Increased Uptake	8,640,000	8,640,000	8,640,000	8,917,500	8,917,500	8,917,500

Abatement Measure 8 – District heating

District heating has the potential to substitute thousands of small combustion appliances with a few large sources. The switch to large (MW) scale combustion allows implementation of several technologies that are not normally viable at small scale. These include gas CHP, biomass CHP, biomass heat only, Energy from Waste (either thermal treatment or biological treatment of waste) and reclamation of waste heat from existing sources (e.g. power stations or industrial processes).

The BAU assumption for the numbers of homes connected to district heating is based on current uptake of district heating and is limited to around 200,000 homes in the UK. BBAU take up is based on a review of recently published reports and consultation documents such as those for the Renewable Energy and Heat and Energy Saving Strategies and assumes some 4.8 million homes are connected to district heating systems by 2030.

This measure will generate direct emissions for a new sector (district heating) while reducing direct emissions in the domestic sector. It will also impact on indirect emissions for two reasons. Firstly electricity use for space heating is reduced and secondly electricity generated from this measure will reduce the total amount required.

Business as usual assumptions

District heating is not currently widely implemented in the UK and the renewable heat incentive impact assessment contains no further detail of expected uptake. While there is likely to be investment in combined heat and power (CHP) and communal heating systems arising from the Supplier Obligation and Green Deal, post 2012, this is expected to be at a smaller building/development scale and so is covered in Measure 9, below.

Beyond business as usual assumptions

There is a good deal of interest in district heating arising primarily from the technology's ability to deliver carbon savings in urban environments. A literature review has been conducted in order to establish likely take-up of the measure. A brief review of the reports is included below:

1. The development of district heating in the current market is constrained by considerable market barriers (for example, there are high capital costs and high project risks and the institutions placed to help instigate schemes have little incentive to do so) and no growth is anticipated until these market failures/barriers are addressed.

2. Consultations on CESP, the Heat and Energy Saving Strategy and Renewable Energy Strategy along with developments in planning policy may help stimulate growth in district heating. The consultation documents suggest ambitious levels of district heating will be in place after 2020, however, there is no clear analysis or evidence to suggest targets will be met[23].

3. It is clear that district heating schemes take a long time to implement. In the interim it is anticipated that smaller heating islands will be developed (probably focussed on large institutional heat loads and new development) which can be linked together at a later stage. There is therefore a continuum of district heating systems to consider. This is partially addressed by Measure 9 where we considering smaller communal heating schemes.

4. The prime mover (main heat source) in district heating systems will vary depending on the scale of the system and could include (large to small systems) waste heat from power stations, EfW (incineration), biomass CHP, biogas CHP (from anaerobic digestion or sewage) or natural gas CHP. There is therefore a considerable mix of possible fuels/energy sources and different systems with varying efficiencies to consider. Economic analysis suggests that the most cost-effective heat sources for district heating will be waste heat from CCGT power stations, however, given the importance of developing renewable heat to help the UK meet its Renewable Energy Directive targets there are likely to be strong drivers for the development of renewable heat sources. This aspect of district heating is considered in more detail in the Power Sector chapter.

Table A1.21 below summarises the assumptions used for current (effectively 2025 BAU), 2025 BBAU and maximum potential for district heating in the UK. For 2030, we have assumed the same quantum of homes will be affected as set out below.

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[23] Numerous studies conclude that there is considerable technical potential within the existing built environment for district heating. These studies do not fully consider the considerable potential in new development nor how new development can be used as a launchpad for district heating nor how effective emerging policies will be at breaking down barriers to district heating. Essentially, none pf the studies considers the speed/timeline for implementation of district heating in any detail, only the maximum long term potential is considered.

Table A1.17 BAU and BBAU installations of district heating

	Current (2025 and 2030 BAU)	2025 and 2030 BBAU	Maximum Potential
Number of homes connected to district heating	200,000	4,850,000	7,000,000
New homes connected to district heating	0	1,250,000	1,500,000
Existing homes connected to district heating	200,000	3,600,000	5,500,000
Total heat sales from district heating (TWh)	1.5	47	90
Waste heat from CCGT power stations (TWh)	0.2	4.7	5
EfW (incineration) (TWh)	0.7	15.5	46
Biomass CHP (TWh)	0.0	11.3	30
All biogas (AD + sewage gas) (TWh)	0.0	4.2	15
Gas CHP	0.8	11.3	90

Table Notes:

1. Maximum potential for number of homes and total heat sales largely guided by *The Potential and Costs of District Heating Networks April 2009*.
2. Maximum potential from different fuels guided by Renewable Energy Strategy (total of maximum potential for each fuel exceeds total maximum potential for all district heating i.e. fuels are in competition)
3. 2025 BBAU assumptions are ambitious but represent considerable reductions (~50%) compared to Renewable Energy Strategy
4. Proportions of BBAU market share for different heat sources in 2025 guided by Renewable Energy Strategy

Methodology and other assumptions

The approach to assessing impacts from district heating is similar in principle to the approach used to assess fuel switching. The following impacts are identified:

- The amount of domestic combustion displaced assumes 90% of heat supplied from district heating displaces heat produced by gas boilers with 90% efficiency and that 10% of heat generated displaces electrical heating with 100% efficiency.
- The emissions factors for domestic gas combustion are used to quantify air quality impacts per kWh of gas displaced and emissions factors derived from the power sector are used to quantify air quality impacts per kWh of electricity displaced. Reductions in direct and indirect emissions have been

calculated separately to allow reductions to be assigned to the domestic or power sectors as appropriate.

- Fuel consumption to generate heat in the district heating prime mover is calculated based on the following thermal efficiencies: Gas CHP – 42%, Biomass CHP – 63%, Biogas CHP – 48%, EfW – 50%.

Emissions factors have been calculated as follows.

Table A1.18 Approach to calculating emissions factors

Fuel	Emissions factor
Natural gas in domestic boilers	Calculated from NAEI 2020 predictions for emissions and energy use in the domestic sector
Grid electricity	Calculated from NAEI 2020 predictions for power sector emissions and UEP38 predictions for electricity demand in 2020
Biogas in large CHP	Calculated from NAEI 2020 predictions for emissions
Biomass in large CHP	Calculated as per power sector see section A1.3.2
Waste in large CHP	Calculated from NAEI 2020 predictions for emissions assuming a CV of 10.4MJ/kg for MSW
Natural gas in large CHP	Calculated from NAEI 2020 predictions for emissions from the power sector but disregarding figures for PM (see section A1.1)

Emissions factors are generally calculated per unit fuel combusted but in the case of grid electricity, the average emissions per unit energy generated by the grid has been calculated

Further benefits are calculated based on the amount of electricity generated from district heating. This displaces electricity that would be generated in the power sector. The following electrical efficiencies have been assumed: Gas CHP – 38%, Biomass CHP – 17%, Biogas CHP – 32%, EfW – 30%. Emissions factors derived from the power sector are used to quantify air quality impacts per kWh of electricity displaced. Again, these emissions have been quantified separately so that they can be assigned to the power sector.

The capital costs of prime movers are largely taken from *The Potential and Costs of District Heating Networks, 2009*. These costs have been updated to 2011 prices[24]. Costs are per kWe (derived from thermal and electrical efficiencies and assuming an 8,000hr run time) and £/kWe for Gas CHP – £719, Biomass CHP – £3,832, Biogas CHP – £8,481, EfW – £9,581. The capital costs of district heating infrastructure are based on £6,000 per home (the number of affected homes is taken from Table A1.17).

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[24] For reference, the original costs, from the *The Potential and Costs of District Heating Networks, 2009* were £/kWe for Gas CHP – £657, Biomass CHP – £3,500, Biogas CHP – £7,745, EfW – £8,750.

Running cost impacts can be complex for district heating schemes as there are numerous transfers to consider. AMEC have calculated running costs based on a societal model rather than from an investor perspective. Costs taken into account include the cost of fuel used in district heating, the value of electricity produced from CHP, and the benefits of displaced fuel usage. Potential income streams from ROCs and LECs are not considered nor are heat sales from district heating to householders (all of these transactions are effectively transfers).

These have been calculated using the following factors (these differ from domestic energy prices as district heating operators will have greater purchasing power). The costs have been taken from *The Potential and Costs of District Heating Networks, 2009*[25]

Gas	£20/MWh
Biomass	£20/MWh
Electricity sale price	£50/MWh
Income from EFW gate fee (for biogas and incineration)	£4/MWh

Note that costs have not been disaggregated between domestic/power/district heating sectors as this is not feasible.

Abatement Measure 9 – CHP and biomass for individual homes/blocks/developments

Building/development scale biomass and CHP

Some of the technologies appropriate for district heating can be implemented at a smaller scale (primarily gas CHP or biomass heat only). This can be for individual homes (e.g. in the case of micro CHP (~1kWe) or biomass stoves (~5kW)) or more likely at a development scale (e.g. small communal biomass heating systems (~100kW) or gas CHP (~20kWe) serving a block of flats or individual housing developments of ~50+ homes).

Current uptake of such systems in the UK is negligible although policies such as the Supplier Obligation (post 2012) are anticipated to contribute to BAU growth in this sector. BBAU take-up based on a review of recently published reports and consultation documents such as those for the Renewable Energy and Heat and Energy Saving Strategies.

This measure will impact on indirect emissions for two reasons. Firstly electricity use for space heating is reduced and secondly electricity generated from this measure will reduce the total amount required.

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[25] The costs have been updated to 2011 prices using the retail prices index and are those used in the calculations.

Business as usual assumptions

A detailed assessment of the market for small scale CHP and biomass in new build, including consideration of sensitivity to a number of key issues in the definition of zero carbon, has been completed by the Renewables Advisory Board[26]

The report reveals considerable sensitivity around the definition of zero carbon for these technologies and also assumes that micro CHP will be a viable technology. The baseline anticipated BAU from this report is summarised below, although the baseline has been converted from approximate number of installations to approximate number of homes affected.

Table A1.19 BAU Take-up of micro/small/medium biomass and CHP in new build

Technology	Number of new homes using this technology per year to 2016	Number of new homes using this technology per year post 2016
Biomass (including micro, small and development scale systems)	~4,250	~13,200
Gas CHP (including micro, small and development scale systems)	~1,450	~68,200

Table Notes:

1. Converted from number of installations in RAB to number of homes. Assumes average biomass boiler serves 25 homes and average medium CHP serves 50 homes
2. Excludes homes identified by RAB as connecting to large scale systems

It is also anticipated that there will be some take up of these measures in existing buildings as a result of the the Supplier Obligation and (Green Deal post 2012) to consider CHP and district heating (anticipated to be implemented initially on a building or development scale rather than true district wide heating).

Beyond business as usual assumptions

The BAU expansion in use of these technologies is driven by a combination of new build and retrofitting to existing homes with retrofitting dominating. There is most scope to retrofit biomass and gas CHP to existing high density developments such as to the ~3million[27] purpose built low and high rise flats in the UK (although communal biomass systems are also being retrofitted in rural off gas grid areas at present). Table A1.20 shows the BBAU installations resulting if all possible installations could be completed by 2025 (supported by many of the

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[26] Renewables Advisory Board, the role of onsite energy generation in delivering zero carbon homes, 2007.

[27] Source: English Home Condition Survey.

same policies that promote district heating) and that the split between homes heated by biomass and homes heated by CHP is 50:50.

Note that there is considerable overlap between this measure and Measure 8 (District heating) as flats with common heating systems would be prime candidates for connection to larger district heating schemes. It is entirely plausible that schemes may first install shared heating systems using low carbon systems and then connect to district heating at some point in the future. As above, we have assumed the same quantum of take up in both 2025 and 2030.

Table A1.20 BAU and BBAU take-up of micro/small/medium biomass and CHP

Technology	Cumulative BAU installations to 2025 and 2030 (both new and existing buildings)	Cumulative BBAU installations to 2025 and 2030
Biomass (including micro, small and development scale systems)	982,250	1,482,250
Gas CHP (including micro, small and development scale systems)	1,182,950	1,682,950

Methodology and other assumptions

It is assumed that 90% of heat being displaced is currently supplied by gas heating with 90% efficient boilers. The remaining 10% of heat is assumed to be displacing 100% efficient electric heating. CHP and biomass system efficiencies are assumed to be as follows:

- CHP electrical efficiency 25%,
- Thermal efficiency 50%,
- Biomass thermal efficiency 87%

The following estimates have been applied for system costs, CHP £250/home, biomass boiler £1,200/home, and conversion costs (including plant rooms): £6,000 per home. Running costs are calculated from a societal perspective based on domestic scale costs for gas, electricity (assuming all electricity generated is used on site and so provides economic savings at full market value) and biomass.

A1.6 Summary of measures and costs

Table A1.21 shows the estimated costs of each abatement technology for the domestic sector and the associated reduction in emissions. The domestic sector does not lend itself easily to standard approach used in other sectors which sets out measures based on take-up, emissions reduction efficiencies, etc. This is especially the case where a measure spans multiple sectors (e.g. many of the insulation measures impact across the domestic sector and also on the power sector) and so data is not included for percentage reduction efficiencies or percentage market penetration as in some sectors.

Table A1.21 Summary of beyond BAU abatement measures for the Domestic Energy sector for 2025 and 2030 [1]

Abatement measure	Future uptake of measure (%)		Operating life (years)	Capital Costs (£k, 2011 prices)		Annual operating costs (£k, 2011 prices)		Total annualised costs (£kpa, 2011 prices) -	
	2025	2030		2025	2030	2025	2030	2025	2030
Fuel switching away from coal and oil	100%	100%	42	7,692,000	8,926,000	-86,000	-106,000	381,000	436,000
Homes heated with natural gas switch to heat pumps	4%	6%	20	16,835,000	22,848,000	-69,000	-91,000	1,116,000	1,517,000
Combined effect of cavity wall insulation	76%	77%	42	20,338,000	1,686,000	-625,000	379,000	307,000	465,000
Increased uptake of loft insulation top up from 150mm	25%	25%	42	1,556,000	1,606,000	-102,000	-106,000	-31,000	-32,000
Increased uptake of loft insulation top up from 100mm	90%	90%	42	62,000	64,000	-9,000	-9,000	-6,000	-6,000
Combined effect of loft insulation top up	90%	90%	42	1,619,000	1,671,000	111,000	-115,000	-37,000	-38,000
Combined effect of increased uptake of Solid Wall Insulation	24%	23%	36	21,568,000	21,568,000	-2,649,000	-2,641,000	-1,586,000	-1,578,000
Increased uptake of A rated boilers	78%	78%	15	1,970,000	1,635,000	-170,000	-113,000	31,000	29,000
Increased uptake of Solar Water Heating (Combined effect)	30%	30%	20	35,745,000	36,891,000	-30,000	-32,000	2,485,000	2,563,000
Increased uptake of domestic PV electricity	30%	30%	25	48,576,000	49,048,000	-4,000	-4,000	2,944,000	2,972,000
Combined Effect of District Heating	17%	16%	50	40,929,000	40,929,000	-1,772,000	-1,772,000	-28,000	-28,000
Combined effect of small CHP/Biomass	11%	11%	30	7,473,000	7,473,000	-225,000	-225,000	181,000	181,000

Notes: The costs presented here are the average costs for each abatement measure (in case a measure was given a range of costs. All costs rounded. A discount rate of 3.5% is considered in the analysis.

Table A1.22 Summary of beyond BAU abatement measures efficiency for the domestic energy sector

Abatement measure	Reduction in 2025 emissions (kt)						Reduction in 2030 emissions (kt)					
	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3
Fuel switching away from coal and oil	2.4	31.4	2.2	5.9	7.5	n/a	2.9	39.2	2.8	7.4	9.3	n/a
Homes heated with natural gas switch to heat pumps	0.0	-0.2	0.0	0.0	0.1	n/a	0.4	-0.2	0.0	0.0	0.1	n/a
Combined effect of cavity wall insulation	1.2	1.3	0.3	0.6	1.4	n/a	0.7	0.9	0.2	0.4	0.8	n/a
Increased uptake of loft insulation top up from 150mm	0.4	0.3	0.1	0.2	0.4	n/a	0.3	0.4	0.1	0.2	0.4	n/a
Increased uptake of loft insulation top up from 100mm	0.0	0.0	0.0	0.0	0.0	n/a	0.0	0.0	0.0	0.0	0.0	n/a
Combined effect of loft insulation top up	0.4	0.4	0.1	0.2	0.4	n/a	0.4	0.5	0.1	0.2	0.5	n/a
Combined effect of increased uptake of Solid Wall Insulation	5.2	5.7	1.4	2.5	5.7	n/a	4.9	6.5	1.4	2.6	5.8	n/a
Increased uptake of A rated boilers	0.3	0.0	0.0	0.0	0.0	n/a	0.2	0.0	0.0	0.0	0.0	n/a
Increased uptake of Solar Water Heating (Combined effect)	1.5	1.9	0.4	0.8	1.8	n/a	1.5	2.2	0.5	0.9	1.9	n/a
Increased uptake of domestic PV electricity	3.7	1.5	0.1	0.1	0.1	n/a	1.9	0.9	0.1	0.0	0.0	n/a
Combined Effect of District Heating	-16.3	0.4	0.0	-0.0	0.3	n/a	-16.3	0.4	0.0	-0.0	0.3	n/a
Combined effect of small CHP/Biomass	-2.2	0.1	0.0	-0.0	0.1	n/a	-2.2	0.1	0.0	-0.0	0.1	n/a

A1.7 References

1. The key references used to investigate this sector are referenced throughout this chapter and summarised below:
2. 2010 National Atmospheric Emission Inventory (NAEI) provided by AEA
3. Updated Energy and Carbon Emissions Projections (UEP43), January 2012
4. Building Research Establishment, Domestic Energy Fact File, 2003
5. Building Research Establishment, Domestic Energy Fact File, 2008
6. BERR – The current status and prospectus for microgeneration technologies
7. Department of Communities and Local Government. 2012 National Planning Policy Framework (NPPF).
8. Department of Energy and Climate Change (DECC). January 2012.Estimates of Home Insulation levels in GB.
9. Department of Energy and Climate Change (DECC) 2012. Feed In Tariff (FIT) - Consultation of Comprehensive Review Phase - tariffs for solar PV.
10. DECC, Energy Act 2011: Green Deal Impact assessment.
11. DECC Quarterly Energy Prices, December 2008.
12. Department of Energy and Climate Change (DECC) 2011, Renewable Heat Incentive (RHI) Impact Assessment.
13. Department of Energy and Climate Change (DECC) 2011, UK Renewable Energy Roadmap http://www.decc.gov.uk/assets/decc/11/meeting-energy-demand/renewable-energy/2167-uk-renewable-energy-roadmap.pdf
14. Energy Savings Trust, Ground Source Heat Pumps http://www.energysavingtrust.org.uk/Generate-your-own-energy/Ground-source-heat-pumps
15. Renewables Advisory Board, The Role of Onsite Energy Generation in Delivering Zero Carbon Homes, 2007
16. The Potential and Costs of District Heating Networks, 2009

A2. Contents

A2. Power Stations

A2.1. Sector profile

Table A2.1 presents the emissions from power stations developed by AEA, based on DECC's UEP43 forecasts and the 2009 baseline National Atmospheric Emissions Inventory (NAEI). Projections for particulate matter (PM), NOx and SO_2 emissions from existing coal power stations, and SO_2 emissions from existing oil-fired power stations are based on plant by plant forecasts, which have been made available for use in this study (DECC,2011c). Projections for the remaining fuels/plants/pollutants are developed and available at an aggregated level.

Table A2.1 NAEI emissions projections for power stations in 2025 and 2030

Source Name	Activity Name	2025 Emissions (kt)						2030 Emissions (kt)					
		NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3
Power stations	Poultry litter	0.7	0.2	0.0	0.0	0.0	na	0.7	0.2	0.0	0.0	0.0	na
Power stations	Straw	0.2	0.1	-	-	0.0	na	0.2	0.1	-	-	0.0	na
Power stations	Coal	27.2	24.5	0.2	0.6	0.3	na	13.7	11.1	0.1	0.3	0.1	na
Power stations	Liquid bio-fuels	0.0	0.0	0.0	0.0	0.0	-	0.0	0.0	0.0	0.0	0.0	-
Power stations	Sour gas	0.0	0.0	0.0	0.0	0.0	-	0.0	0.0	0.0	0.0	0.0	-
Power stations	Wood	2.0	0.0	0.2	0.4	0.5	-	2.0	0.0	0.2	0.4	0.5	-
Power stations	MSW	4.9	0.5	0.1	0.1	0.0	na	5.8	0.6	0.1	0.1	0.0	na
Power stations	Petroleum coke	1.7	5.2	0.1	0.2	0.0	-	1.7	5.2	0.1	0.2	0.0	-
Power stations	Natural gas	31.9	0.6	0.8	0.8	1.1	-	26.4	0.5	0.7	0.7	0.9	-
Power stations	Landfill gas	23.7	-	0.3	0.3	0.4	-	19.4	-	0.2	0.2	0.3	-
Power stations	Sewage gas	1.6	-	0.1	0.1	0.1	-	1.7	-	0.1	0.1	0.1	-
	TOTAL	93.9	31.1	1.8	2.4	2.3	-	71.7	17.6	1.5	2.0	1.9	-

The projections include zero activity (and therefore zero emissions) for combustion of the following fuels in power stations in both 2025 and 2030: coke, fuel oil, gas oil, LPG, OPG, orimulsion, slurry, scrap tyres and waste oils.

na = not available

From the above projections, key sources of NOx emissions in the power sector are coal and natural gas power stations, and combustion of landfill gas and municipal solid waste (MSW) for energy. The analysis for this sector has focussed on the emission sources of coal and natural gas combustion because it is assumed that energy from waste plants (incinerators) already have very tight regulatory limits placed on them by the Waste Incineration Directive (now part of the Industrial Emissions Directive) such that the BAU take-up of selective non-catalytic reduction (SNCR) in this sector should already be at – or very close to – maximum feasible uptake.

The principle source of SO_2 emissions from the power sector is coal power stations; therefore the analysis has focussed only on these stations.

Key sources of $PM_{2.5}$ and PM_{10} emissions from the power sector are, according to the NAEI projections, natural gas, landfill gas, coal and wood combustion. It is surprising that the projected PM emissions from natural gas combustion are this high, because "particulate matter emissions from gas turbines burning natural gas are not an environmental concern under normal operation and controlled combustion conditions" (European Commission, 2006). Following discussion with Defra and AEA it was agreed that abatement measures for this source would be investigated, as well as emissions of particulates from coal power stations.

The largest source of VOC emissions from power stations is from the combustion of natural gas, which is considered in this analysis.

The UK coal power sector comprises a fleet of existing coal power stations, many of which are expected to close by 2025 either having opted-out of the Large Combustion Plant Directive (LCPD), as a result of the subsequent Industrial Emissions Directive (IED) or policies and measures aimed to reducing greenhouse gas emissions. DECC's UEP43 projections also include new-build coal power stations, some of which is forecast to have carbon capture and storage (CCS). Although the UK also has some peak load oil-fired power stations projected to operate in 2025 and 2030 in the plant by plant UEP43 projections, the NAEI projections (Table A2.1) show zero oil combustion in 2025 and 2030. A number of natural gas-fired power stations operate in the UK, most of which are combined cycle gas turbines (CCGTs), with the remainder comprising open cycle gas turbines (OCGTs).

A2.1 Business as Usual Policies and Abatement Techniques

The UEP43 projections take into account the impacts of the following policies:

- Large Combustion Plant Directive (LCPD) until 2016;
- Industrial Emission Directive (IED) 2016 onwards;
- EU-ETS Carbon Price and Carbon Price Floor; and
- Renewable electricity targets.

The key assumptions relevant from year 2020 for the electricity supply industry (AEA, 2007) are presented below:

- Plant operations are constrained by environmental limits and the IED applies;
- Some closure of non-opted out coal capacity is assumed. New coal-fired plants are assumed to be fitted with SO_2 and NOx clean up equipment (AEA, 2007);
- The projections assume that new coal stations with the ability to collect and store carbon dioxide will be built by 2020; and

- Imports of electricity are assumed to increase. Similarly the availability of new interconnection capacity allows for increased export levels in the future.

In order to comply with the emission limit values (ELVs) set by the LCPD and IED, flue gas desulphurisation (FGD) will be fitted to all coal fired power stations and selective catalytic reduction (SCR) to the majority of coal fired and a small number of gas fired power stations before 2025. The control of PM emissions from coal fired power stations using electrostatic precipitators (ESP) and/or bag filters is also expected under business as usual. A number of existing coal fired power stations are forecast to convert to be wholey fired by biomass in response to the policies listed above.

A2.2 Beyond Business as Usual

2.2.1 Abatement Techniques

Electrostatic Precipitators

Electrostatic precipitators (ESPs) are common industrial devices for particulate control in power stations. They demonstrate excellent particulate removal from gas streams, with design efficiencies sometimes exceeding 99.8% (Zhu, 2003). In an ESP, a high voltage is applied across the discharge electrodes and two earthed parallel collecting plates. Applying a strong field around the discharge electrodes induces electrical breakdown in the passing flue gas, and negative ions stream to the collecting electrodes. The particles become electrically charged and are subjected to an electrostatic field. Deposits on the collecting electrodes are removed through agitation and fall by gravity into hoppers (Wu, 2001).

It is assumed that most coal power stations in the UK already have ESPs installed. These ESPs can however be upgraded, through for example the addition of fields or flue gas conditioning. This will have an additional abatement efficiency compared to the BAU installation. For the purposes of this analysis, the addition of one further ESP field is considered as a measure. Cross media effects are assumed to be zero.

This measure is assumed to apply to all existing coal power stations (ELV and NERP plants), as well as to new build coal power stations. This represents maximum feasible uptake.

Costs are taken from Wu (2001) and have been updated to 2011 prices, and are presented in Table A2.2. For the purposes of this analysis the average of the costs from measures (b) and (c) have been used. The lifetime of an additional ESP field is assumed to be 15 years. The assumed abatement efficiency for both $PM_{2.5}$ and PM_{10} is 49% taking the average of measures (b) and (c). Measure (a) is not used as the costs are not in a comparable unit.

Table A2.2 Assumed costs for an additional ESP field

Measure	PM abatement efficiency	Capital cost (£, 2008 prices)	Operating cost (£, 2008 prices)	Source
(a) Additional ESP field	70%	£5,344,785 (Note 1)	£0.62 / MWh	Wu (2001)
(b) Additional ESP field	40%	£9,518 / MWe	£159 / MWe / year	Wu (2001)
(c) Additional ESP field with flue gas conditioning	57%	£11,501 / MWe	£293 / MWe / year	Wu (2001)

Note 1: for a moderate ESP with a specific collection area of 54 $m^2/m^3/s$.

Switching to coal with lower sulphur content

The sulphur content of coal is variable and is directly responsible for the SO_2 emissions from a coal-fired plant. By lowering the average percent sulphur content of the coal used, the total emissions of SO_2 will be reduced. Imported coal is generally of lower sulphur content than that available from certain Member States, with internationally traded coal being widely available at sulphur levels of 0.8% and below and down to 0.1% (Entec, 2005). Shifting to lower sulphur coal is a technically feasible measure, but it does raise some fundamental wider factors, including:

- The security and diversity of energy supplies of particular Member States;
- The potential economic impacts on the EU coal mining sector; and
- The environmental impacts of additional transportation of fuels and any potential negative impacts on other pollutants (although there may be positive impacts for some pollutants).

At a more site specific level, the key issues would relate to any potential future price premia for lower sulphur coals, potential costs of boiler and/or ESP modifications, and impacts on installed flue gas desulphurisation equipment. The latter technical aspects are briefly considered below.

- *Boiler modifications*. Usually, a switch from one coal type to another is often possible with the existing burners. However, it is reported (JEP, 2003) that boiler modifications would be anticipated to allow the long term burning of lower sulphur coals.

- *ESP modifications*. For coals with a low sulphur content the resulting fly ash normally exhibits high electrical resistivity, which may significantly reduce ESP performance, whereas a high ash content in the coal will increase the ash load and may strain the ash handling system. Flue gas conditioning (FGC) aims to reduce fly ash resistivity and/or to increase fly ash cohesivity through the injection of small quantities of chemical reagents (most commonly sulphur trioxide and / or ammonia) into the flue gas ahead of the ESP (Zhu, 2003). JEP (2003) suggest that the requirement for ESP modifications would not be necessary in switching to 0.8% sulphur coals, but would be necessary in switching to lower sulphur coals e.g. 0.4%.

- *Flue gas desulphurisation*. The operational efficiency of FGD equipment may be impaired by the use of very low sulphur coals. Additionally with respect to FGD performance lower inlet levels of SO_2 to the FGD will result in lower outlet levels, though the percentage reduction may not be the same depending on specific performance.

- *Milling plant modifications.* Modifications to milling plant "will depend on the plant and the nature of fuel involved. Some stations may need little work for some coals, but for other ultra low sulphur coals significant work could be required. The costs for mills depend on mill safety to date and expected with the new fuel"[1] are need for Indonesian coals and costs may be high for safety throughout the plant. Similar modification may be needed on plant to allow use of the highest volatile matter bituminous coals.

- *Impact on SCR.* Some of the low sulphur coals may not be compatible with SCR due to potential for fouling of the catalyst.

DECC UEP43 projections incorporate projections for the percentage sulphur content of coal used in power stations on a plant by plant basis for existing installations and aggregated for new installations. The weighted average sulphur content for coal used in the UK power stations in 2025 is 0.90% and in 2030 is 0.91%.

Using the assumption that UK indigenous coal has an average sulphur content of 1.5%[2], and that imported low sulphur coal is available at a sulphur content of 0.4%, the fractions of indigenous and imported coals that comprise the UK average of 0.91% were derived (46% indigenous coal, 54% imported coal). Due to the wider issues described above, it was assumed that a maximum feasible uptake of switching to increased imported low sulphur coal would comprise fractions 10% indigenous, 90% imported. This would result in a UK average of 0.51% sulphur content in coal, which represents an average SO_2 abatement efficiency for this measure of 44% (assuming no impacts on flue gas desulphurisation).

Costs for switching to low sulphur coal have been obtained from IIASA's GAINS model (scenario NEC_NAT_CLEV4), where specific UK costs can be extracted from the model (GAINS, 2008). The assumed cost (updated to 2011 prices) per tonne of SO_2 abated pre-FGD is £366. It is expected that the GAINS cost does not include potential impacts that may occur such as impacts on the FGD, SCR, ESP or the milling plant. An additional cost of £5/kW is suggested by Mott MacDonald (2004) as a possible additional cost to undertake plant modifications to deal with the increased volatile content of the low sulphur Indonesian coals. Other costs were suggested by JEP, but full details have not been disclosed upon request and so could not be verified.

Fuel data collected from all coal power stations in England and Wales has been obtained from the Environment Agency[3]. These data include the monthly coal tonnage combusted for 2000-2011 and the percentage sulphur content of this coal for each month. The fact that some plants are reported to already be using coal with sulphur content less than 0.5% in certain months indicates that the possible additional costs of using low sulphur coal has

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[1] Personal Communication with Joint Environment Programme (JEP), 13th March 2009

[2] IEA Coal Power Database suggests current sulphur contents of domestic fuels to average 1.49%; also Mott McDonald (2004) projects UK sulphur contents to 2016 on page B-1.

already be borne by these installations under BAU. Therefore BBAU capital costs have only been applied to those installations with no historic use of coal with sulphur content less than 0.5%.

As an SO_2 abatement measure, this measure is unlikely to be implemented in addition to improved FGD, although it is technically feasible. Note that this measure will increase dependency on imported coals from Indonesia and Russia, and that the issue of security of supply (which does not feature in the cost benefit analysis) needs to be taken into account.

Flue gas desulphurisation

Flue gas desulphurisation (FGD) is a proven suite of technologies for effective SO_2 control. The majority of plants use wet scrubber FGD systems rather than dry or semi-dry processes (Wu, 2003). UK coal power stations (not opted out under the LCPD) have already installed FGD.

Two measures are considered in this analysis to improve the SO_2 abatement efficiency of existing FGD systems:

- An additional spray bank stage in the scrubbing process. This could improve an existing SO_2 abatement efficiency from 87.5% to 95%. This would involve breaking into the scrubbing vessels and so would incur a capital cost. Additional power consumption costs would dominate the increased operational costs; and

- The use of chemical additives in wet scrubber FGD systems. This could improve an existing SO_2 abatement efficiency of 87.5% by 2 to 3 percentage points, in the case where scrubber chemistry is the limiting factor in SO_2 removal (as opposed to mechanical design or condition (AEP, 2011)). It is also not appropriate for less common FGD systems using the sea water scrubbing process, due to the need to remove the additives from the waste waster stream. This is likely to incur a capital cost for upgrading the waste waster treatment plant. Operational costs will also be increased.

Although FGD is primarily an SO_2 abatement technique, it can also abate dust emissions by typically 50%. However, it is expected that an improvement to an existing FGD system would have minimal additional dust abatement. This is reasoned below for wet processes and dry and semi-dry processes:

- Wet scrubber FGD plant is usually fitted after the fly ash particulate collection plant (typically ESPs) to ensure that fly ash particulate loading to the FGD plant is minimised, in order to protect FGD by-product gypsum quality. Some fly ash going in to the FGD plant is captured in the spray section; however, what comes out at the back-end of the FGD plant tends to comprise uncaptured fly ash and some dry gypsum product that can be carried over from the FGD plant. An additional spray stage to increase SO_2 capture may result in a marginal increase in fly ash capture within the FGD system but this is expected to be minimal.

- A dry or semi-dry FGD process using a lime reagent would generally rely on an ESP after the scrubbing stage to collect the reaction products arising from the FGD process. Enhanced deSOx performance of a dry or semi-dry FGD system is generally achieved by increasing the quantity of lime relative to the SO_2 level in the flue gas. Whilst this would increase the loading of particulate on the ESP, the performance of the ESP is relatively insensitive to the particulate loading and so particulate emissions are unlikely to be affected.

The increased power requirements of an additional spray bank lead to increased CO_2 emissions; it is assumed that the percentage CO_2 penalty is equivalent to the percentage increase in power consumption.

The waste water treatment plant is likely to require upgrading if chemical additives are used, in order to add a further aerobic treatment stage to remove the organic acid additives. There are no existing plants currently applying this measure and so there is a high degree of uncertainty attached to these cost estimates. Other concerns which require further scoping include technical difficulties in conditions of variable effluent flow and or of high salinity, and any impacts on the quality of the gypsum. As an alternative to biological treatment, 'zero discharge technologies' (involving evaporation and crystalisation) are likely to incur high capital and operating costs.

FGD is assumed to be fitted as BAU to the entire coal sector by 2020. Thus this measure of improving the efficiency of existing FGD systems has been applied to the entire sector (maximum feasible uptake). Costs supplied by in-house experts, and consulted on in previous editions of the MPMD, are provided as additional fractions compared to costs of whole FGD systems, and are presented in Table A2.3. The lifetime of this measure is assumed to be 15 years.

Table A2.3 Assumed costs for FGD, and improved FGD (costs additional to existing systems)

Measure	SO_2 abatement efficiency	Capital cost (£, 2011 prices)	Operating cost (£/year, 2011 prices)
Existing FGD (wet)	87.5%	£142,000 / MWe	£11,000 / MWe
Improved FGD (an additional spray bank stage in the scrubbing process)	40% (additional)	£7,200 / MWe	£820 / MWe
Improved FGD (the use of chemical additives) and additional water treatment	20% (additional)	£5,100 / MWe	£650 / MWe

Selective Catalytic Reduction

A beyond BAU measure for NOx abatement for some coal power stations is retrofitting selective catalytic reduction (SCR). This is also a measure considered for CCGT plants.

SCR is based on the reduction of NOx with ammonia or urea in the presence of a catalyst. It relies on injecting the reagent at a point in the flue gas ductwork system at which there is an appropriate temperature window. This is a significant issue which complicates (and increases the costs) of retrofitting this technique. Ammonia is more commonly used as the reducing agent than urea, as it is cheaper to purchase, thus reducing operating costs. The catalysts used can be heavy metal oxides, zeolites, iron oxides or activated carbon. There are three configurations of SCR, namely high-dust, low-dust and tail end. The high-dust arrangement is the most commonly implemented because it avoids flue gas reheating due to the high operating temperature of the catalyst (European Commission, 2006).

Retrofitting SCR to CCGTs typically has a much higher cost than that retrofits to coal plant due to the large civil and mechanical works required (JEP, 2001). In order to locate the SCR unit, the heat recovery steam generator (HRSG) would usually have to be demolished and re-built, along with significant alterations to the boiler house.

The NOx emission reduction efficiency of SCR can be up to 90% or more, but depends on levels of NOx achieved by primary measures in place (European Commission, 2006); typically it is 80% (JEP, 2001).

Cross-media effects of SCR include ammonia slip, in which ammonia is released in the flue gas due to incomplete reactions of ammonia with the NOx. Emissions of ammonia (NH_3) from SCR are however believed to be below 5 mg/Nm^3 (LCP BREF, 2003), and so no increases in ammonia emissions from coal stations is modelled, in-line with AEA NH_3 emission factors from coal combustion that do not assume increases with SCR plant. Similarly, ammonia sulphates may be deposited on the downstream facilities, and NH_3 may also occur in FGD waste waters and the air heater cleaning water and in the fly ash (European Commission, 2006). The resources required to produce NH_3 for use in SCR can be an issue, as large volumes of natural gas are required. There is limited data available on emissions of nitrous oxide (N_2O) from SCR in power stations. However, Yates *et al*. (2005) confirm that for some catalysts, N_2O formation can increase with typical SCR catalyst loading. The additional on-site power requirements of the SCR unit will lead to marginal increases in SO_2 and CO_2 emissions.

The retrofitting of SCR to coal power stations is a BBAU measure for 1.0 GW of coal capacity in 2025 and 0.6 GW in 2030 (estimated from UEP43, data provided by Defra (2010) and AMEC (2012)). Costs are presented in Table A2.4. Fixed operating costs include catalyst replacement costs and variable operating costs include ash sales lost and ammonia costs.

Retrofitting SCR to CCGTs is assumed to be a BBAU measure to most of the sector. A small number of plant are assumed to fit SCR under BAU in response to the IED (AMEC, 2012) and it is unlikely that all remaining plant would retrofit SCR due to its high costs and the age of installation by 2025/2030 (with closure being an alternative). A conservative uptake of 75% is modelled. Costs are presented in Table A2.4. 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.

Fitting SCR to new build CCGTs is assumed to be a BBAU measure. Due to space constraints in retrofitting SCR to existing CCGTs the capital costs can be assumed to be considerably lower for new build. JEP (2001) provide capital costs of new build CCGT including SCR, whilst BERR**Error! Bookmark not defined.** have provided apital costs of new build CCGT without SCR. Capital costs have been taken from BERR[4], but also agree with ES & Redpoint (2008). The time value of bringing forward capital costs is included in the analysis, rather than the capital costs themselves. Operational costs have been calculated based on the operational efficiency gains and therefore represent fuel (and thus cost) savings. Fuel cost assumptions were based on BERR 2008. The time value of bringing forward the costs related to lost revenue during decommissioning and construction was included in the analysis.

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[4] Personal Communication with BERR, 2nd May, 2008

The lifetime of the measure is assumed to be 15 years. Costs have been taken from JEP (2001), but due to high variation in alternative cost estimates (see section 'SCR costs based on other sources of cost data' below), **these costs are taken as central values and a +/-30% range applied to them**.

Table A2.4 Assumed costs for SCR to coal and CCGTs

Measure	NO_X abatement efficiency	Capital cost (£, 2011 prices)	Fixed operating cost (£/year, 2008 prices)	Variable operating cost (£, 2008 prices) (Note 1)	Source
SCR retrofit to coal plant	80%	£88,200 / MWe	£3,500 / MWe	£0.81 / MWh	JEP (2001)
SCR retrofit to CCGT	80%	£109,000 / MWe	£2,600 / MWe	£0.05 / MWh	JEP (2001)
Additional SCR to CCGT new build	80%	£77,500 / MWe (Note 2)	£2,600 / MWe (Note 3)	£0.05 / MWh (Note 3)	JEP (2001)

Note 1: JEP (2001) gives variable operating costs in £ / MWhr – this has been assumed to be MWhr electrical.
Note 2: This capital cost is the additional cost of fitting SCR to a new build CCGT compared to a new build CCGT without SCR. It has been obtained from new build CCGT including SCR (£495,778 / MWe; JEP, 2001) minus the cost of new build CCGT without SCR (£425,000 / MWe; BERR, personal communication).
Note 3: The fixed and variable operating costs of SCR in new build are assumed to be equal to the operating costs of SCR when retrofitted. The variable operating cost will change however if a new CCGT replaces an existing CCGT.

SCR costs based on other sources of cost data

A review of different data sources has been undertaken, including:

- the BREF LCP document (European Commission, 2006): presents SCR cost data for coal fired power stations in relation to waste gas flow rates;
- EGTEI: presents the costs of retrofitted SCR to coal power plants based on cost data (from about 2000) for two French power stations; and
- AEP5: provided capital cost estimates from various power plants (mainly in the US).

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.

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

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

Replacing existing coal stations with new CCGTs

Replacing an existing coal power station with new-build CCGT can be considered a multi-pollutant abatement measure.

Due to the zero sulphur content of natural gas, this measure effectively has a 100% SO_2 abatement efficiency. Particulate emissions from natural gas combustion are very low, normally well below 5 mg/Nm^3 (European Commission, 2006) and so an assumed PM_{10} and $PM_{2.5}$ abatement efficiency is 99%. NOx emissions are reduced both through combustion and from efficiency techniques, combining to give 69% NOx abatement efficiency[6].

Defra (2003), in the guidelines for participants in the ETS, provide CO_2 emission factors for coal and for natural gas combustion. The difference in these emission factors indicates that the cross media effect of replacing coal power stations with new CCGTs is a CO_2 abatement efficiency of 37%.

Due to data scarcity, the cross media impact on CH_4 has not been quantified, although qualitatively there are two counteracting impacts: that coal mining has an associated CH_4 emission, as do natural gas networks.

Coal plant closure and new CCGT build is considered a BBAU measure for the entire existing coal sector (NERP and ELV approaches). However, it is unlikely that the entire existing coal sector would close and re-build due to security of supply and other factors. A conservative uptake of 50% of existing coal power stations has been modelled.

Existing coal power stations are assumed to operate at 37.5% electrical efficiency in 2020[7]; new build CCGT in 2020 are assumed to operate at 56.7% net, derived from Mott MacDonald (2010). A NOx abatement efficiency of 51% has been adopted[8]. Capital costs have been taken from BERR[9], but also agree with ES & Redpoint (2008). A proxy for modelling the measure was used for the current study, that of the cost of replacement, modelled as follows:

- CAPEX: The information with regards to the baseline scenario closure dates of the plants considered is highly uncertain. Previous DECC modelling provides summary information up to 2030, but at that stage a large number of plants are assumed to continue operating and therefore assumptions are required with regards to their closure dates beyond 2030. Therefore, in order to produce a more accurate estimate of CAPEX than previously considered, it is possible to make assumptions about

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[6] Calculated from comparing NOx emission factors for coal and CCGT sectors in the NAEI projections.

[7] Updated from 36% used previously after comments from the Joint Environment Programme that efficiencies should improve from 36% to 37-38% due to steam turbine retrofits.

[8] Calculated from comparing NOx emission factors for coal and CCGT sectors in the NAEI projections.

[9] Personal Communication with BERR, 2nd May, 2008

closure dates – e.g. all coal plants closing in 2025 or 2030, or all coal fired stations would operate for 60 years. The time value of money of bringing forward the new investment from the baseline scenario of the CAPEX year would be divided equally between the years that the investment is brought forward for (and the emissions savings are accumulated).

- Decommissioning costs would be ignored as there are no published estimates for such costs and it is expected that these costs would vary significantly across existing plants.
- Lost revenue in the years between closure and opening: would be calculated as outlined in Box 1.
- Operating margin difference: would be calculated as outlined in Box 1.

Box 1 Method description of closure and replacement measures

Commercial investment decisions in CCGT entail an expected lifetime of 20 years. This means that the capital expenditure (CAPEX) for most CCGT stations would be recovered by 2020. However, many of these plants are expected to continue operating beyond 2020, as suggested by closure assumptions made in 2008 by BERR or in reports commissioned by BERR (e.g. Redpoint et al). This is similar for coal: among the 14 coal fired stations considered, only two will be under the age of 40 and only one will be under the age of 35 in 2020.

In a complex electricity system like that of the UK, the closure and opening of new plants is affected by a large number of variables for example:

- portfolios of electricity companies,
- the type of other electricity plants in the system (e.g. renewables and the requirement to provide a complement to the intermittent electricity they supply or the proportion of gas and the way it interacts with gas supply volumes and gas prices).
- the technical availability of CCS for coal as compared to gas will also affect whether an operator would choose to replace coal with gas.

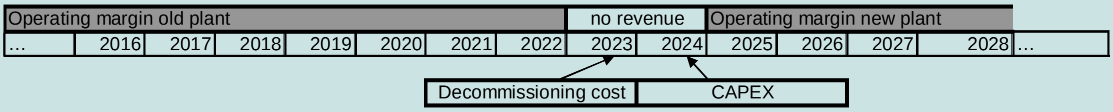
Therefore, in order to estimate the costs of 'closure and replacement' measures, it is necessary to make assumptions and / or simplifications. A simplifying assumption is that the existing coal and CCGT stations would be replaced in the baseline scenario with CCGT stations anyway and the measure simply brings forward this closure and investment. In this case all the costs for the closure and re-opening are allocated to the individual plant closed. In this case the costs associated with the two measures could be classified as follows:

i. CAPEX: the time value of money related to bringing forward the capital cost of building the new CCGT to 2020 from the baseline construction time.
ii. Decommissioning: The time value of money related to the decommissioning cost of the old CCGT or coal plant early.
iii. Lost revenue in the years between closure and opening: The time value of money related to the cost or lost revenue associated with stopping the operation of the old plant and starting the operation of the new plant – e.g. in 2 years time.
iv. Operating margin difference: The difference in the margin of operating an old power station and the new power station. For CCGT to CCGT replacement this figure is negative – i.e. this element constitutes net savings due to the higher efficiency of the new plant.

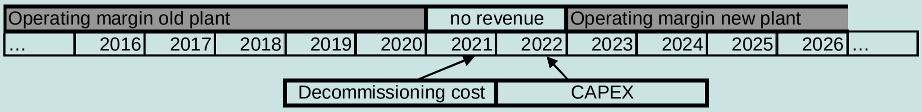
It would be assumed that decommissioning would last for one year, with decommissioning costs incurred immediately after closure, and that construction would last for one year, with capital costs for new capacity incurred one year after the closure of the old plant and one year before the new plant starts operation.

An example of a timeline of this approach is presented below:

Baseline scenario



Closure and replacement



Fuel costs have been calculated based on the operational efficiency gains and the fuel cost differential therefore represent fuel (and thus cost) savings. Annual fixed and variable operating costs for coal and CCGTs have been taken from ES & Redpoint (2008), and the difference between the two fuelled plants obtained.

The economic lifetime of the new plants is considered to be 20 years – this is the period of time that the capital costs are spread across. The costs are presented in Table A2.5.

Table A2.5 Costs of coal closure and re-open new CCGT (£m, 2011 prices)

Measure	NO_X abatement efficiency	CAPEX (£/MWe)	Fixed operating cost (£/MWe/yr)	Variable operating cost (£/MWe/yr)	Source
Close old coal and re-open new CCGT	51%	465,000	-20,000	14	BERR, and ES & Redpoint (2007)

This measure can be (and has been) considered in partnership with new-build CCGT with SCR.

Carbon capture and storage

Carbon capture and storage (CCS) involves capturing carbon dioxide (CO_2) emitted when burning fossil fuels, transporting it and storing it in geological formations, including depleted oil and gas fields, coal seams and aquifers. Capture technologies are based on three generic approaches: pre-combustion, post-combustion and oxyfuel. Many of these technologies are at an advanced stage of development; however, as yet, no commercial-scale CCS power station has been developed. For new build coal fired power stations most studies indicate that any of the three capture technologies discussed below could be applicable before 2020. It has been assumed that each measure is applied to all new coal plants as BBAU in three separate scenarios.

The estimated costs for emerging technologies such as CCS have a high degree of uncertainty, and a generalised cost does not account for site specific costs which may be considerable. For example, CO_2 injection well costs increase exponentially with depth; the difference between injection to an aquifer at 800 metres depth and a 4000 metre-deep depleted gas field could differ by a factor of between 5 and 10 (OECD/IEA, 2004).

Post combustion capture

Post-combustion capture, via the adsorption process, is the most well developed technique. CO_2 is separated from the flue gas stream using a liquid solvent (typically amines). The solvent is processed to recover the CO_2 for transport and storage. Conventional abatement techniques for NO_x, SO_x and PM (i.e., SCR, FGD and ESP) are essential measures prior to the removal of CO_2 from the exhaust gas stream due to the interaction of the acidic gases and the sorbents used for CO_2; these react to form stable, non-regenerable salts, and therefore cause a steady loss of the amine (IPCC, 2005). One of the purposes of full scale demonstration plants is to better understand the effect of NOx, SOx and PM in the flue gas on CO_2 sorbent degradation and the maximum acceptable levels.

There are two factors affecting the overall emissions:

- The concentration at which solvent degradation will occur; and
- The energy penalty of the capture technology, which requires more fuel to be burnt to generate the same amount of electricity.

For coal-fired plants with 90% CO_2 captured, calculations derived from EEA (2011) and UEP43 projections indicate that these factors will result in a decrease in NO_x emissions of 31 per cent, and a decrease in SO_x emissions of 99 per cent, compared to similar plants without CCS.

The use of amine sorbents for CO_2 capture could lead to a five fold increase in NH_3 emissions compared to a state of the art coal plant without post-combustion capture (VROM, 2008). Furthermore, the increase in fuel consumption could lead to an increase in PM emissions of around 20 per cent (EEA, 2011).

Using data from Parsons Brinckerhoff (2011) the capital cost premium of the addition of post combustion capture to a new, conventional (advanced supercritical (ASC) pulverised coal with FGD) power station is 1.23 £m/MWe. The operational cost premium is 72 to 103 £k/MWe, including CO_2 transport and storage costs.

Pre combustion capture

The primary fuel is processed with steam and air/oxygen to produce a carbon monoxide and hydrogen "synthesis gas" (syngas) which is further reacted to produce a CO_2 and hydrogen mix. The CO_2 is separated for storage and the hydrogen used as a fuel. Prior to the separation of the CO_2 the gas is desulphurised via the removal of H_2S, and PM and NH_3 are removed using conventional methods. The process for removal of H_2S is an adsorption method, which results in a reduction in SO_x emissions on combustion of the hydrogen rich gas.

This method is strongly associated with the Integrated Gasification Combined Cycle (IGCC), in which the hydrogen produced is combusted in a gas turbine and heat is recovered from the exhaust gases to generate superheated steam to drive a steam turbine. As an efficient method of using coal, IGCC results in a reduction of NO_x compared to conventional pulverised coal (European Commission, 2007b).

For IGCC plants with 90% CO_2 captured, calculations derived from EEA (2011) indicate that these factors will result in a decrease in NO_x emissions of 72 per cent, and a decrease in SO_x emissions of 43 per cent, compared to similar plants without CCS.

Using data from Parsons Brinckerhoff (2011) the capital cost premium of an IGCC with pre-combustion compared to a conventional (advanced supercritical (ASC) pulverised coal with FGD) power station is 1.85 to 2.72 £m/MWe. The operational cost premium is 81 to 115 £k/MWe, including CO_2 transport and storage costs.

Oxyfuel combustion

In oxyfuel combustion the fuel is combusted in a mixture of nearly pure oxygen and recycled flue gases, rather than air, to produce a flue gas that is mainly CO_2 and water vapour. This exhaust is cooled to condense and remove the water and to purify the CO_2 for storage. The absence of air during combustion reduces the NO_x formation during combustion to a level associated only with nitrogen compounds in the fuel, with a net reduction of ~75% for coal and only trace amounts of NO_x produced with natural gas combustion. SO_x and PM levels in the combustion exhaust are not affected, however, the low temperature purification will result in the removal of >60% of NO_x and >90% of SO_x and PM, avoiding the requirement for alternative abatement technologies.

Parsons Brinckerhoff (2011) does not assess the cost os oxyfuel combustion. However, a comparison of costs in Mott MacDonald (2012) indicates that the levelised cost of electricity from oxyfuel combustion is 0-1% lower than from post combustion CCS in 2020 and 1-3% lower in 2028. Therefore in the MPMD the total annualised cost for oxyfuel combustion has been set to be 1.5% less than that of post combustion capture CCS.

Increased biomass co-firing

Co-firing of biomass with coal is a mature technique, but to date there has been limited uptake in the UK. The amount of biomass cofired in coal power stations is not presented in the UEP or NAEI projections. NAEI projections of coal consumption in power stations are marked as confidential and not disclosed by AEA; in previous editions of the MPMD the difference between this and the coal consumption in the DECC plant by plant UEP projections has been used to indicated the amount of biomass co-fired in coal plant. In UEP38, the BAU scenario is for 0.9 % (by energy) co-firing of biomass in coal fired plants by 2020 (DECC, 2008). For lack of more recent data this value has been assumed in this assessment. The main driver for combustion of biomass is that the electricity generated can be considered as renewable and will contribute towards targets to increase renewable generation and reduce CO_2 emissions. Installations may also increase co-firing under BAU in order to help achieve the ELVs under the IED.

There is a wide range of materials that could be considered for biomass co-firing, including domestically produced agricultural waste such as straw and chicken litter; domestic energy crops such as willow and rape; and imported products such as olive stones. Although these sources can be considered to be renewable, there is a finite supply and increasing demand across Europe will affect availability and cost of supply. The performance of different fuels is dependant on a number of factors including the moisture content and energy density, but in general a greater volume of biomass is required to produce an equivalent amount of energy when substituted for coal. Consequently there are practicality and cost issue considerations for storage, transport and fuel preparation.

With co-firing there are risks and concerns of increased ash deposition, and the change in composition of the ash increasing boiler corrosion and reducing the effectiveness of SCR catalysts. Experience indicates that a large scale power station can substitute coal with 20% biomass (by energy) for co-firing (IEA, 2005b). The fuel preparation requirements for biomass differ from coal; since coal is more brittle the mills are designed to crush the coal, whereas biomass is more fibrous and requires cutting. Trials by E.On (2004) indicate that co-milling biomass and coal is achievable up to 20% (by mass) for certain types of biomass. The calorific value for most types of biomass is approximately half that of coal, and so these trials indicate that co-milling can be performed for up to 10% (by energy) biomass, which is consistent with Doosan Babcock (2007). Modification to the mills may be required to ensure that milling can be performed safely, due to the higher volatility of biomass.

When co-firing more than 10% biomass, direct injection is the most viable method and has been operated successfully on a commercial basis in a small number of applications across Europe. In this case the biomass is milled separately and injected either directly into the furnace or injected into the pulverised coal pipework prior to the burner. This method requires the installation of biomass mills and additional fuel delivery pipework.

For this assessment two BBAU scenarios have been included for biomass co-firing:

- 10% by energy, via co-milling; and
- 20% by energy, via direct injection.

During co-firing, SO_2 emissions decrease, normally in direct proportion with the amount of biomass used, as most sources of biomass contain far less sulphur than coal (IEA, 2005b). NO_x and PM emissions are more variable, with experience indicating either a small increase or small decrease depending on the type of biomass used and the firing conditions (IEA, 2005b and DTI, 2005b). Therefore this analysis has assumed that there is 100% reduction in SO_x and no impact on NO_x or PM. As highlighted in the UK Biomass Strategy, there are substantial gaps in reliable emissions data for biomass combustion and consequently high uncertainty attached to these assumptions. Under the EU ETS and Renewables Obligation biomass is considered to be ‘carbon neutral’ and therefore a 100% decrease in CO_2 emissions has been assumed.

AEA forecast future biomass prices at 4 to 10 £/GJ. UEP43 central forecast coal price is 70 £/tonne for 2020 onwards, and DUKES indicates that coal used in power stations has a net calorific value of 24 GJ/tonne. This indicates that the price premium for biomass is around 4 £/GJ. The price of Renewable Obligation Certificates (ROCs) is not included in this assessment as ROCs represent a transfer of costs rather than an actual cost.

A report for DTI (2003) states that the capital costs will be modest, and therefore for the co-milling scenario the cost has been taken as zero as it is assumed that any necessary equipment modification is undertaken as part of the standard maintenance regime for existing plants, or as part of the standard capital costs for new build plants. Under the direct-firing scenario, the 20% uptake will result in installation costs for additional biomass bulk storage and milling facilities, along with installation of direct injection co-firing systems. These costs have been based on developments at Drax to install 400 MW_{th} of biomass co-firing capacity at a cost of £28 million (Drax Power Ltd, 2008).

Conversion to biomass

As an alternative to co-firing, coal fired power stations could converted to 100% biomass firing. Certain power stations have indicated that this is an option that they are considering for some or all of their units. According to a 2011 study from Arup on behalf of DECC, up to 11 existing coal-fired units could be converted to 100% biomass under a high uptake scenario, with 5 units converted under a medium scenario (DECC, 2011b), with a cumulative installed capacity of 8031 GWh per year in 2020.

The study indicates that the main technical development which would facilitate this is the torrefaction (a type of thermochemical pre-treatment) of biomass, as this would reduce the need for changes to the fuel milling and handling systems. A potential limiting factor is the consideration for new CCS build as an alternative option.

As in the measures above for biomass co-firing, a 100% decrease in CO_2 emissions has been assumed, along with 100% reduction in SO_x and no impact on NO_x or PM.

The capital costs for 100% conversion are taken from the Arup study, which quotes £598,000/MWe (Decc, 2011b). The same operating costs are assumed as for co-firing, giving a central additional cost of biomass at 4 £/GJ.

Large-scale CHP for community heating

There are currently a large fleet of existing CCGT power stations around the country, very few of which utilise CHP. The heat made available from CHP for hot water and space heating can be provided for a range of end-users, which can include new housing development, existing households (at greater cost), public sector and commercial premises. The benefits of introducing district heating (or community heating) is to utilise the waste heat that is produced by the power station and use this to provide hot water to end-users, displacing their need to heat water on-site, and through the efficiencies of scale, reduce emissions.

A measure has been developed to retrofit CHP to existing CCGT power stations and pipe the heat to the community, based on the example for Barking Power Station. Constraints are proximity of power stations to communities and areas earmarked for growth (i.e. regeneration that provides new housing makes a stronger business case for laying down pipe work).

The Digest of UK Energy Statistics 2008 has been used to compile a list of gas CCGT power stations[10]. Stations less than $20MW_e$ were excluded. This left 42 stations, of total capacity 26.4 GWe. Of these, some are assumed to already have CHP installed (Baglan Bay, Barking[11], Derwent, Shotton, Immingham, Saltend and Fellside), leaving 35 stations with CHP of total capacity 22.3 GWe.

Due to the constraints placed on the potential to use heat from a power station to heat a community that comprises at least some new build, the following assumptions were used to choose likely candidates for CHP retrofit:

- All 35 stations were spatially identified, and if they were located within 10 km of a sizable population, they were deemed to be of sufficient proximity;
- All of the 35 station locations in England (28) were compared to those areas identified by Communities & Local Government as being Growth Areas or Growth Points[12], and if they were co-located then they were deemed to have sufficient new build;
- Of the remaining 7 stations in Wales, Scotland and Northern Ireland, due to lack of specific information on growth areas[13], it was assumed that growth areas were those areas around existing conurbations; and
- If the power station was both of sufficient proximity to a sizable population, and if that area was considered a growth area, then the power station was identified as being suitable for CHP retrofit.

This process identified 21 stations, of total capacity 14 GWe that could apply the measure. The assumptions on costs for the measure have been derived from the Barking Power project, after discussions with the London

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[10] Table 5.11 Power Stations in the United Kingdom (operational at the end of May 2008)

[11] Although Barking does not have CHP already installed, it is currently being planned and so is considered BAU.

[12] http://www.communities.gov.uk/documents/housing/pdf/898634.pdf

[13] Housing documents for Scotland (http://www.scotland.gov.uk/Resource/Doc/201716/0053780.pdf) and for Wales (http://wales.gov.uk/dpsp/wspatialplan/documents/wsp2008update/wsp2008updatee.pdf?lang=en) were consulted.

Development Agency[14], and from in-house expertise. The assumptions are set out below in Box 2. Given these assumptions, the number of households that are expected to be provided with heat is close to 600,000. Although this is much lower than the figure of 4.4-6.5m households that could potentially be supplied by district heating networks economically (Pöyry, 2009), this larger figure takes into account provision of heat through all different technologies. For a consideration of other CHP techniques, please see the Domestic chapter (A4).

Box 2 Assumptions for Barking Power Station that will connect to the London Thames Gateway Heat Network

Factor	**Assumption**		**Source**
Capacity of power station	1000	MW_e	DUKES
Heat available	165	MW (16.5%)	LDA[14]
Heat demand per household	4	kW	LDA[14]
Number of households supplied	41,250		(derived)
CAPEX – Power station modifications (to the steam supply system)	£2.5m		LDA[14]
CAPEX – Substation (controls, pumping, water treatment)	£10m		LDA[14]
CAPEX – 23km pipe network	£55m		LDA[14]
Economic lifetime of CHP plant	30	years	LBBD (2007)
Economic lifetime of pipe work	50	years	LDA[14]
Length of main transmission pipe	0.56	metre/house	(derived)
Unit cost of main transmission pipe	£2,400	per metre	(derived)
Length of pipe connections to each house from the main transmission pipe	10	metres	AMEC expert
Unit cost of pipe connections to each new household from the main transmission pipe	£1,000	per metre	AMEC expert
Unit cost of pipe connections to each existing household from the main transmission pipe	£1,500	per metre	AMEC expert
Fraction of households benefiting from district heating that are new build	50%		AMEC expert

In order for such a project to get off the ground, the heat sold must be no more expensive than existing heating costs, therefore it is assumed that the heat from the CHP plant will be at the same cost as existing heating. It is anticipated that the heat supply price of £6.20 / MWh (LBBD, 2007), i.e. at a competitive rate, will internalise the additional operating costs incurred of operating the CHP equipment, and that there is no need to consider the operating costs at a societal level. The pipe work is not expected to incur significant operating costs due to its long lifetime (50 years).

Emissions benefits are assumed to lie in NO_X and CO_2 savings. Around 90% of households use gas to heat their homes in urban areas, and so it is assumed that this measure replaces gas-fired home boilers to gas powered CCGT. As such, PM and SO_2 emissions should already be negligible. The aim of the Cogeneration Directive is to reduce CO_2 emissions, through the energy savings from increased heat utilisation. NO_X emissions are however also expected to be reduced, as well as the displacement of NO_X emissions from urban background to emissions from the power station stack, contributing to an improvement in local air quality. A NO_X emission factor for domestic boilers has been calculated at 0.092g/kWh. Using the NO_X emission factor from the electricity produced from

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[14] Personal Communication with the LDA, 28th April 2009.

CCGT stations from the UEP43 DECC data, taking into account a drop in electrical efficiency gives a NO_X emission factor for the heat produced as 0.032g/kWh. [15] This results in a NO_X abatement efficiency of 65%. Average annual household heat demand is assumed to be 11,700kWh for existing homes and 6,600kWh for new homes.[16] Careful reporting is necessary due to the fact that domestic emissions are reduced whilst emissions from the power station increase slightly (due to electrical efficiency losses). The emission reductions reported in this database for this measure are a combination of both the domestic reduction and power sector increase.

CO_2 savings are similarly calculated: a CO_2 emission factor for gas-fired CCGT at 47.6% efficiency is taken from DTI (2007a), at 449g/kWh. Adopting the same approach as for the emission factor for heat described above, a CO_2 emission factor for heat from CCGT CHP is estimated to be 54 g/kWh, compared to a value of 206 g/kWh for domestic gas boiler combustion. This results in a NO_X abatement efficiency of 74%.

Table A2.6 Assumed NO_X and CO_2 abatement efficiencies and costs for retrofitting CHP to existing CCGTs

Measure	Capital cost (£, 2008 prices)		Operating cost (£, 2008 prices)	Source
Retrofit CHP to CCGT	Plant modifications	£15,000 / MWe	None (Note 1)	LDA
	Substation	£61,000 / MWe		LDA
	Main transmission pipe work	£2,400 / m	None	LDA
	Household pipe work	£1,250 / m	None	AMEC

Note 1: assumed to be subsumed in the heat sold to the end-user, which is at a competitive rate

Nuclear

There are four possible measures for the replacement of fossil fuel generation with nuclear generation:

- Build new nuclear instead of building new coal;
- Build new nuclear instead of building new CCGT;
- Early closure of existing coal and build new nuclear; and

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[15] This value is from 99 TWh electricity produced, and 26.4 kt NOx: assuming that the CCGT electrical efficiency is 47.6%, but that it drops by two percentage points in CHP mode (AMEC expert opinion), gives an electricity NO_X factor of 0.278g/kWh. The NO_X factor for the heat is therefore the difference in 0.278 and 0.266g/kWh, multiplied by the ratio of electrical generation to heat generation (45.6% vs. 16.5%), giving 0.032g/kWh for the heat.

[16] Assuming existing UK home GAS consumption for space heating and hot water in 2020 is 42GJ (home heating efficiency 90%) (derived from NAEI activity projections); and new UK home GAS consumption for space heating and hot water in 2020 is 24GJ (home heating efficiency 92%) (based on AMEC experience in new housing building regulations).

- Early closure of existing CCGT and build new nuclear.

The generation of electricity using nuclear power stations does not result in direct emissions of NOx, SO_2, PM or VOC. However, safety systems at nuclear power plant include back up generators which are normally run on gas-oil. The replacement of coal fired power stations with nuclear plant therefore results in a significant, but not total, reduction in emissions. If nuclear power stations replace gas fired power stations there is a reduction in NOx emissions, however the use of gas oil back up generators leads to an increase in emissions of SO_2 and PM.

The standard load factor of different electricity generation methods is different, as indicated in the following table.

Table A2.7 Electricty generation load factors and costs (£$_{2011}$)

Type	Load factor		Source	Capital cost	Operating cost	Source
	2025	2030		(£/kW$_e$)	(£/MWh$_e$)	
Nuclear	85%	85%	DTI, 2007b	1500	16	DTI, 2007b
Existing coal	38%	34%	UEP43	n/a	33	Royal Accademy of Engineers, 2004
New coal	83%	26%	UEP43	1000	33	Royal Accademy of Engineers, 2004
Existing CCGT	40%	36%	UEP43	n/a	45	Parsons Brinckerhoff, 2011
New CCGT	64%	53%	UEP43	670	45	Parsons Brinckerhoff, 2011

To calculate the cost of a nuclear power station, compared to a fossil fuelled power station, the first step is to establish the capacity that would be required in order to provide the same amount of electricity, by comparing the load factors. The capital cost for the options in which new nuclear is selected instead of new coal or CCGT capacity is taken as the incremental cost. In the options for early closure of fossil generation and replacement with nuclear, the whole cost of the new build is included. In all options only the incremental operating costs are used in the MPMD.

Non-thermal renewables

There are four possible measures for the replacement of fossil fuel generation with non-termal renewables:

- Build new renewables instead of building new coal;
- Build new renewables instead of building new CCGT;
- Early closure of existing coal and build new renewables; and
- Early closure of existing CCGT and build new renewables.

Non-thermal renewables include onshore and offshore wind, solar, hydro and marine. Such renewable sources do not produce emissions of NOx, SO_2, PM or VOC, so the uptake of such technologies in place of coal or gas fired power stations will result in a reduction of these pollutants.

The approach taken to calculate the cost of these options is the same as that described above for the nuclear options. For the cost calculations the renewable generation selected is assumed to be composed of 50% onshore wind (of which 33% is 50 kW to 5 MW and 66% >5MW) and 50% offshore wind (of which 50% is <100MW and 50% is >100MW) based on forecasts by Intelligent Energy Europe (2009). The load factor and costs used for wind for the purpose of comparison against fossil generation are presented in the following table.

Table A2.8 Electricity generation load factors and costs (£$_{2011}$)

Type	Load factor		Capital cost	Operating cost	Source
	2025	2030	(£/kW$_e$)	(£/MWh$_e$)	
Non-thermal renewables (wind)	34%	34%	1600	0.03	Arup, 2011

2.2.2 Summary of Measures and Costs

Table A2.9 summarises the estimated cost of each abatement measure for the power sector. The costs in the summary table are based on the average cost of each abatement measure. The range of costs were summarised in the relevant subsections of Section 2.2.1.

Table A2.102.10 presents the reduction efficiency of the abatement measures and the associated reduction in emissions.

Table A2.9 Summary of beyond BAU abatement measures for the power sector

Abatement measure	Future uptake[1] of measure (%)		Operating life (years)	Capital costs (£k, 2011 prices)		Annual operating costs (£k, 2011 prices)		Total annualised costs (£kpa, 2011 prices)	
	2025	2030		2025	2030	2025	2030	2025	2030
Additional ESP field	100%	100%	15	105,997	69,391	2,279	1,492	11,483	7,517
Low sulphur coal (from UK average of 0.91% to UK average of 0.51%)	96%	98%	15	18,059	4,321	37,664	17,479	39,232	17,854
Improved FGD (additional spray banks in the scrubbing process)	77%	56%	15	52,576	29,935	6,066	3,454	10,631	6,053
Improved FGD (chemical additives)	77%	56%	15	42,429	26,072	5,342	3,283	9,026	5,546
Retrofit SCR	10%	11%	15	87,629	58,223	6,415	4,116	14,024	9,172
SCR retrofit to CCGT (JEP) (75% uptake)	75%	73%	15	2,481,041	2,353,683	63,772	59,949	279,188	264,308
Coal Closure and reopen CCGT (50% uptake)	50%	50%	20	39,976	25,855	311,213	216,962	351,189	242,817
Coal Closure and reopen CCGT with SCR (50% uptake)	50%	50%	20	na	na	320,369	221,727	378,646	257,208
New build as IGCC with pre-combustion capture (CCS)	27%	16%	30	3,558,478	3,558,478	148,404	148,404	341,883	341,883
New build as PC with oxyfuel (CCS)	27%	16%	30	na	na	na	na	234,257	234,257
New build as PC with post-combustion CCS	27%	16%	30	1,899,282	1,899,282	134,558	134,558	237,824	237,824
Increased biomass co-firing (co-milling)	8%	6%	na	0	0	119,468	45,662	119,468	45,662
Increased biomass co-firing (direct injection)	15%	11%	15	328,165	207,465	238,936	91,324	267,429	109,337
Biomass conversion	46%	22%	20	1,752,140	1,644,500	710,378	337,507	833,661	453,216
Large scale CHP for community heating	70%	71%	30, 50[2]	8,121,154	8,121,154	0	0	405,790	405,790
New nuclear build instead of coal	27%	16%	40	752,413	-826,753	-191,868	-60,095	-168,305	-110,480
Close existing coal and open nuclear	37%	40%	40	2,431,239	2,143,293	-238,115	-135,085	-124,267	-34,721

Abatement measure	Future uptake[1] of measure (%)		Operating life (years)	Capital costs (£k, 2011 prices)		Annual operating costs (£k, 2011 prices)		Total annualised costs (£kpa, 2011 prices)	
	2025	2030		2025	2030	2025	2030	2025	2030
Close existing CCGT and open nuclear	91%	71%	40	15,232,545	15,589,673	-4,105,358	-3,207,681	-3,392,059	-2,477,659
New nuclear instead of CCGT	9%	27%	40	1,736,830	790,731	-1,586,770	-1,497,987	-1,537,008	-2,995,973
New renewables (non-thermal) build instead of coal	100%	100%	25	4,593,919	376,445	-305,715	-95,753	-17,234	-63,163
Close existing coal and open renewables (non thermal)	100%	100%	25	7,387,056	5,724,089	-379,403	-215,239	68,800	132,064
Close existing CCGT and open renewables (non-thermal)	100%	100%	25	40,681,522	41,635,303	-4,102,568	-3,205,453	-1,890,660	-941,686
New renewables (non-thermal) instead of CCGT	100%	100%	25	15,188,064	13,198,983	-1,585,596	-1,496,903	-759,800	-779,257

Note 1: Uptake defined as the percentage, by capacity, of the NAEI sector-activity (i.e power stations-coal or power stations-natural gas) to which the measure applies, additional to what is expected under BAU.

Note 2: Two components: substation works: 30 years, pipework: 50 years

na = not available: for example if total annualised cost is presented in source data without capital and operating costs presented separately, or if the total annualised costs are calaculated from data based on cost per tonne of pollutant abated.

Table A2.10 Summary of beyond BAU abatement measures efficiency for the power sector

Abatement measure	Emission reduction efficiency (%)						Reduction in 2025 emissions (kt)						Reduction in 2030 emissions (kt)					
	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3
Additional ESP field	0	0	49	49	0	0	0.0	0.0	0.12	0.27	0	0	0.0	0.0	0.06	0.14	0	0
Low sulphur coal (from UK average of 0.91% to UK average of 0.51%)	0	44	0	0	-	-	0.0	10.3	0.00	0.00	-	-	0.0	4.8	0.00	0.00	-	-
Improved FGD (additional spray banks in the scrubbing process)	0	40	0	0	0	-	0.0	7.8	0.00	0.00	0	-	0.0	2.6	0.00	0.00	0	-
Improved FGD (chemical additives)	0	20	0	0	0	-	0.0	4.1	0.00	0.00	0	-	0.0	1.2	0.00	0.00	0	-
Retrofit SCR	80	0	0	0	0	-	1.4	0.0	0.00	0.00	0	-	1.2	0.0	0.00	0.00	0	-
SCR retrofit to CCGT (JEP) (75% uptake)	80	0	0	0	0	-	19.1	0.0	0.00	0.00	0	-	15.9	0.0	0.00	0.00	0	-
Coal Closure and reopen CCGT (50% uptake)	51	100	99	99	-	-	3.5	6.2	0.06	0.14	-	-	1.4	2.2	0.03	0.06	-	-
Coal Closure and reopen CCGT with SCR (50% uptake)	90	100	99	99	-	-	6.2	6.2	0.06	0.14	-	-	2.5	2.2	0.03	0.06	-	-
New build as IGCC with pre-combustion capture (CCS)	72	43	0	0	-	-	5.2	2.8	0.00	0.00	-	-	1.6	0.8	0.00	0.00	-	-
New build as PC with oxyfuel (CCS)	90	90	90	90	-	-	6.5	5.9	0.06	0.14	-	-	2.0	1.6	0.02	0.04	-	-
New build as PC with post-combustion CCS	32	99	-20	-20	-	-500	2.3	6.5	-0.01	-0.03	-	*	0.7	1.8	0.00	-0.01	-	*
Increased biomass co-firing (co-milling)	0	100	0	0	-	-	0.0	1.9	0.00	0.00	-	-	0.0	0.6	0.00	0.00	-	-
Increased biomass co-firing (direct injection)	0	100	0	0	-	-	0.0	3.8	0.00	0.00	-	-	0.0	1.2	0.00	0.00	-	-
Biomass conversion	0	100	0	0	-	-	0.0	3.0	0.00	0.00	-	-	0.0	4.6	0.00	0.00	-	-
Large scale CHP for community heating	65	-	-	-	-	-	0.3	0.0	0.00	0.00	-	-	0.3	0.0	0.00	0.00	-	-

Abatement measure	Emission reduction efficiency (%)						Reduction in 2025 emissions (kt)						Reduction in 2030 emissions (kt)					
	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3
New nuclear build instead of coal	98	99	99	99	-	-	7.2	6.5	0.07	0.15	-	-	2.2	1.7	0.02	0.05	-	-
Close existing coal and open nuclear	99	99	99	99	-	-	10.0	9.0	0.09	0.21	-	-	5.5	4.4	0.05	0.12	-	-
Close existing CCGT and open nuclear	96	-44	-44	-44	-	-	22.2	-0.2	-0.24	-0.24	-	-	17.7	-0.1	-0.08	-0.08	-	-
New nuclear instead of CCGT	96	-59	-59	-59	-	-	8.4	-0.1	-0.12	-0.12	-	-	7.8	-0.1	-0.03	-0.03	-	-
New renewables (non-thermal) build instead of coal	100	100	100	100	100	100	7.3	6.5	0.07	0.15	-	-	2.2	1.8	0.02	0.05	-	-
Close existing coal and open renewables (non thermal)	100	100	100	100	100	100	10.2	9.1	0.09	0.21	-	-	5.5	4.5	0.05	0.12	-	-
Close existing CCGT and open renewables (non-thermal)	100	100	100	100	100	100	23.1	0.4	0.55	0.55	-	-	17.7	0.3	0.44	0.44	-	-

“-“ refers to instances where there is insufficient, or inconclusive, information available for analysis.

“*” NH_3 emission projections have not been included in the current version of the MPMD and therefore the absolute increase in emissions has not been calculated.

Negative abatement efficiency and reduction indicates an increase in emissions

A2.3 References

1. AEA (2009) *UK Emission Projections of Air Quality Pollutants to 2020.* AEA Group, Didcot.

2. AEA (2007) *The results and assumptions of the 2005 air quality pollutant emission projections.* AEA Energy & Environment, Didcot.

3. AEP (2011) Personal Communication regarding the use of Organic Additives in Flue Gas Desuphurisation processes.

4. AMEC (2012) *IED Impact Assessment – Large Combustion Plants*. Report for Defra.

5. Arup (2011) *Review of the generation costs and deployment potential of renewable electricity technologies in the UK*. Report for DECC

6. CCSA (2011) *A Strategy for CCS in the UK and Beyond*. CCS Association, London.

7. DECC (2007a) *Competition for a Carbon Dioxide Capture and Storage Demonstration Project: Project Information Memorandum*. Available from: http://www.DECC.gov.uk/files/file42478.pdf

8. DECC (2007b) *Digest of United Kingdom Energy Statistics 2007*. Department for Business, Enterprise and Regulatory Reform. Available from: http://www.DECC.gov.uk/energy/statistics/publications/dukes/page39771.html

9. DECC (2010) *DECC Initial Guidance on EU Funding Mechanism "NER300" for Carbon Capture and Storage (CCS) and Renewable Demonstration Projects*. Department for Energy and Climate Change, London.

10. DECC (2011a) Government reaffirms commitment to CCS, Press notice 11/084, 19 October 2011. Available from: http://www.decc.gov.uk/en/content/cms/news/pn_1184/pn_1184.aspx

11. DECC (2011b) Review of the generation costs and deployment potential of renewable electricity technologies in the UK, ARUP

12. DECC (2011c) *plant_by_plant_raw data*. Unpublished.

13. Climate Change Capital (2007) *ZEP: Analysis of funding options for CCS demonstration plants*. Final Report.

14. DECC (2008) *Updated Energy and Carbon Emissions Projections (UEP32)*. Department of Energy and Climate Change (DECC). URN 08/1358. Published November 2008. Available from http://www.DECC.gov.uk/files/file48514.pdf

15. Defra (2003) *Guidelines for the Measurement and Reporting of Emissions by Direct Participants in the UK Emissions Trading Scheme*. Department for Environment, Food and Rural Affairs. UKETS(01)05rev2.

16. Defra (2007) *UK National Emissions Reduction Plan for the implementation of revised Large Combustion Plant Directive (2001/80/EC). Update No. 1, December 2007.* Available from: http://www.defra.gov.uk/environment/airquality/eu-int/eu-directives/lcpd/pdf/lcpd-nationalplan-update1.pdf

17. Defra (2010) *UEP38 coal plants wSCR from Defra220710.xls* Personal communication.

18. DFIU/IFARE (2004) *Assessment of the Air Emissions Impacts of Emerging Technologies – Fact Sheets*. Available from: http://www-dfiu.wiwi.uni-karlsruhe.de/dfiu/dfiu_emtech.htm

19. Doosan Babcock (2007) *Suitability of biomass feedstocks for co-firing in large, pulverised coal, power plant boilers.* Available from http://www.thermalnet.co.uk/docs/WP2C%20Livingston%20Vicenza.pdf

20. DTI (2003) *Development of Low Cost Systems for Co-utilisation of Biomass in Large Power Plant.* Available at http://www.DECC.gov.uk/files/file14933.pdf

21. DTI (2005a) *Optimising CO_2 Capture from Pulverised Coal Plants: Post-combustion capture with amine solvents*

22. DTI (2005b) *Best Practice Brochure: Co-Firing of Biomass*. Available at http://www.DECC.gov.uk/files/file20737.pdf

23. DTI (2007a) *EU Emissions Trading Scheme Phase II Review of New Entrants' Benchmarks – Small Generation Activities*. Entec UK Limited. http://www.DECC.gov.uk/files/file33266.pdf

24. DTI (2007b) *The Future of Nuclear Power*

25. EEA (2011) *Air Pollution impacts from CCS (draft)*

26. Entec (2005) *Preparation of the review relating to the Large Combustion Plant Directive*. A report for the European Commission, Environment Directorate General. Entec UK Limited.

27. Entec (2008) *Multi-Pollutant Measures Database. Final Interim Report: Meeting the NOx National Emission Ceiling for 2010*. A report for the Department for Environment, Food and Rural Affairs. Entec UK Limited.

28. E.On (2004) *UK Experience of Biomass Co-firing*, available from: http://www.iea-coal.org.uk/publishor/system/component_view.asp?LogDocId=81259&PhyDocId=5648

29. ES & Redpoint (2007) *Dynamics of GB Electricity Generation Investment*. Available from http://www.DECC.gov.uk/files/file38972.pdf

30. European Commission (2006) *Integrated Pollution Prevention and Control Reference Document on Best Available Techniques for Large Combustion Plants*. Available from http://ec.europa.eu/comm/environment/ippc/brefs/lcp_bref_0706.pdf

31. European Commission (2007a) *Trade-off in emissions of acid gas pollutants and of carbon dioxide in fossil fuel power plants with carbon capture.*

32. European Commission (2007b) *Sustainable Power Generation From Fossil Fuels: Aiming for Near Zero Emissions From Coal After 2020.* Available from http://ec.europa.eu/energy/energy_policy/doc/18_communication_fossil_fuels_full_ia_en.pdf

33. European Commission (2008) Draft *Proposal for a Directive on the geological storage of carbon dioxide*. Available from: http://ec.europa.eu/environment/climat/ccs/pdf/com_2008_18.pdf

34. European Commission (2010) *Implementation of the CCS Directive*. Available from: http://ec.europa.eu/clima/policies/lowcarbon/ccs_implementation_en.htm

35. GAINS (2008) *Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model*. International Institute for Applied Systems Analysis (IIASA). Available from: http://www.iiasa.ac.at/web-apps/apd/gains/

36. IEA GHG (2005a) *Building the Cost Curves for CO_2 Storage: European Sector*.

37. IEA (2005b) *Fuels for Biomass Co-firing.* Available from http://www.iea-coal.org.uk/site/ieacoal/reportdetails?LogDocId=81395

38. IEA (2007) *Capturing CO2*

39. Intelligent Energy Europe (2009) *Wind Energy: The Facts.* Available from: http://www.wind-energy-the-facts.org/en/home--about-the-project.html

40. IPCC (2005) *IPCC Special Report: Carbon Dioxide Capture and Storage.* Available from: http://www.ipcc.ch

41. JEP (2001) *Assessment of England & Wales electricity sector BATNEEC for NOx*. Joint Environment Programme.

42. JEP (2003) *A review of SO_2 control options and costs*. Joint Environmental Programme (JEP). Env/EEA/92/2003.

43. LBBD (2007) *Establishing a community heating network in Barking Town Centre.* http://www.barking-dagenham.gov.uk/6-living/envir-protect/envir-sustainability/pdf/btc-eea-district-heating-study.pdf

44. Mott MacDonald (2004) *UK Coal Production Outlook: 2004-16*. Final Report for DTI, March 2004.

45. Mott MacDonald (2010) *UK Electricity Generation Costs Update*. Report for DECC.

46. Mott MacDonald (2012) *Potential cost reductions in CCS in the power sector*. Report for DECC.

47. OECD/IEA (2004) *Prospects for CO2 Capture and Storage*

48. Parsons Brinckerhoff (2011) *Electricity Generation Cost Model - 2011 Update (Revision 1)*. Report for DECC.

49. Poyry (2007) *Analysis of Carbon Capture and Storage cost supply curves for the UK* – Report for DTI

50. Pöyry (2009) *The Potential and Costs of District Heating Networks*. A report to DECC. April 2009. http://www.decc.gov.uk/en/content/cms/what_we_do/uk_supply/energy_mix/distributed_en_heat/distributed_en_heat.aspx

51. Royal Accademy of Engineers (2004) *The Cost of Generating Electricity*. Report by PB Power.

52. VROM (2008) *The impacts of CO2 capture technologies on transboundary air pollution in the Netherlands*

53. Wu, Z. (2001) *Air pollution control costs for coal-fired power stations*. IEA Coal Research. CCC/53.

54. Yates, M., Antonio Martín-Luengo, J., Suárez, S. & Blanco, J. (2005) N_2O formation in the ammonia oxidation and in the SCR process with V_2O_5-WO_3 catalysts. *Catalysis Today*: **107-108**, pp. 120-125.

55. ZEP (2008) European Technology Platform for Zero Emission Fossil Fuel Power Plants. *Zero Emission Platform CO2 Capture and Storage (CCS) Matrix of Technologies*. Available from: http://www.zero-emissionplatform.eu/website/docs/ETP%20ZEP/ZEP%20Technology%20Matrix.pdf

56. Zhu, Q. (2003) *Developments in particulate control*. IEA Clean Coal Centre. CCC/73.

A3. Contents

A3. Other Combustion

A3.1. Sector profile

The "other combustion" sector includes combustion in sources which are not large combustion plants with thermal inputs exceeding 50 MW_{th} in the industrial and commercial sources (AEAT, 2009). These include:

- Agriculture – stationary combustion of various fuels including straw and agricultural operations;
- Miscellaneous industrial and commercial combustion of various fuels including natural gas;
- Other industrial combustion of various fuels including coal, fuel oil, LPG, natural gas, petroleum coke and lubricant 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[1]; and
- Public sector combustion of various fuels including coal and natural gas.

Because these smaller plants are not required to report emissions, emissions are estimated using an appropriate literature-based emission factor applied to national fuel consumption statistics taken from DUKES. The NAEI projections indicate that fuel combustion in these sectors are significant sources of NOx, SO_2, PM_{10} and $PM_{2.5}$ as a proportion of the UK's total emission of these air pollutants in 2025 and 2030[2]:

- NOx: combustion of natural gas in other industrial combustion (6%), miscellaneous industrial/commercial combustion (2%) and public sector combustion (1%), as well as combustion of coal in other industrial combustion (1%);
- SO_2: combustion of coal (6%), fuel oil (2%), petroleum coke (2%) and lubricants (1%) in other industrial combustion and coal combustion in public sector (1%);
- PM_{10}: combustion of straw in agriculture (2%); and
- $PM_{2.5}$: combustion of straw (8%) and agricultural operations (5%) in agriculture and combustion of coal (1%), natural gas (1%) and lubricants (1%).

A3.2. Business as usual policies and abatement measures

The sector covers a range of different industries that are covered by a range of policies and legislation. Key legislation that applies to other combustion includes Integrated Pollution Prevention and Control (IPPC) Directive

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[1] Key assumptions presented in AEAT (2009).

[2] The percentages of emissions are the same for 2025 and 2030 unless noted otherwise.

and Large Combustion Directive (LCP) Directive (these Directives being replaced by the Industrial Emissions Directive (IED), due to be transposed in the UK by January 2013). The activities of “other combustion” are likely to be captured as directly associated activities under the IED i.e. they are part of an installation whose main activity is covered under the IED.

In the UK, the most polluting activities and installations (and combustion plants) subject to the IPPC and LCP Directives are regulated and permitted by the Environment Agency for emissions to air, land, water and other environmental considerations; these are classified as Part A1 activities. Local authorities regulate the comparatively less polluting Part A2 activities (multi-media regulation) and the lesser polluting Part B activities (these are regulated for emissions to air only). Medium sized combustion units (20–50 MW_{th}) are regulated by local authorities as Part B activities.

A survey of large combustion plants in the industrial sector (>50 MW_{th} that fall under the LCPD requirements) by Entec (2008) indicated that secondary (end of pipe) abatement measures for reduction of NOx, SO_2 and dust emissions have not been applied to a great extent in the UK. Considering that some time has passed since 2008 and the plants would have had a few years of experience of meeting the LCP and IPPC conditions by now, more abatement measures may have been implemented. However, a direct consultation with operators of small plants under the “other combustion” sector was not carried out under this study due to constraints in time and resources. For this study, the assumption that end of pipe techniques have not been applied (at least extensively) to plants <50 MWth either from the previous MPMD study has been kept. For the purposes of this report it has been assumed that for plants <50 MW_{th} no secondary abatement measures (that would result in a significant reduction in emissions) are installed or will be installed by 2025 and 2030 in the “other industrial combustion” sector. However for primary measures (e.g. combustion modification and switching fuel) IIASA’s online GAINS model was used to develop assumptions on BAU uptake for this sector, as more detailed information on abatement techniques for this sector were not available.

A3.3. Beyond business as usual potential abatement measures

NOx

The following abatement measures have been considered as beyond BAU for the other combustion sector for NOx emissions:

- Combustion modification (CM): this is described in the GAINS model (IIASA, 1998a) and is a combination of low NOx burners, reburning (fuel injection) and combustion optimisation techniques. An abatement efficiency of 50% on NOx emission levels and BAU uptake rate of 15% (i.e. potential BBAU uptake rate is 85%), which results in a 42.5% emission reduction across the sector in 2025 and 2030, are assumed in the analysis;

- Combustion modification & selective catalytic reduction (SCR): In addition to CM, SCR is installed. 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). SCR offers higher NOx removal efficiencies than SNCR. An abatement efficiency of 80% on NOx emission levels is assumed in the analysis;

- Combustion modification & selective non catalytic reduction (SNCR): In addition to CM, SNCR is installed. Application of SNCR to existing installations is simpler compared to SCR and space requirements are mainly related to NH_3 storage. However, SNCR offers lower NOx removal efficiency than SCR. An abatement efficiency of 40% on NOx emission levels is assumed in the analysis.

These measures have been applied to combustion of all fuels in other industrial combustion, public sector combustion and miscellaneous industrial/commercial combustion. Because GAINS provide different abatement costs per fuel type and per sector, the investment costs for the measures were estimated by calculating an emissions-weighted average of abatement cost (see Box 1 for example).

Box 1. Emissions-based average of GAINS NOx abatement costs

For combustion modification to be applied to combustion of all fuels in other industrial, public sector and miscellaneous industrial/commercial combustion, GAINS provided five different NOx abatement costs for:

(1) 6,930.54 €$_{2000}$/ t NOx abated from natural gas in residential, commercial, services, agriculture, etc.
(2) 861.08 €$_{2000}$/ t NOx abated from gasoline and other light fractions of oil in industry;
(3) 296.29 €$_{2000}$/ t NOx abated from heavy fuel oil in industry;
(4) 2,814.27 €$_{2000}$/ t NOx abated from hard coal (grade 1) in industry; and
(5) 403.48 €$_{2000}$/ t NOx abated from natural gas in industry.

Emissions-based weighting has been applied to the aforementioned five GAINS NOx abatement costs based on NAEI projections of NOx emissions from different fuels and sectors:

(a) 28% of total emissions arises from combustion of natural gas in public sector and miscellaneous industrial/commercial combustion;
(b) 7% of total emissions arises from combustion of gas oil, LPG and burning oil in other industrial combustion;
(c) 3% of total emissions arises from combustion of fuel oil in other industrial combustion;
(d) 6% of total emissions arises from combustion of coal in other industrial combustion;
(e) 56% of total emissions arises from combustion of natural gas in industrial combustion and other sources.

The emissions-weighted NOx abatement cost of combustion modification for combustion of all fuels in other industrial, public sector and miscellaneous industrial/commercial combustion was then estimated as the sum of individual GAINS NOx abatement costs multiplied by the emissions-based weight:

(1) x (a) + (2) x (b) + (3) x (c) + (4) x (d) + (5) x (e) = 2,398.59 €$_{2000}$/ t NOx for all fuels in other industrial, public sector and miscellaneous industrial/commercial combustion

Based on this approach, the emissions-weighted average of NOx abatement costs used for this study are: (1) 2,398 €$_{2000}$/ t NOx abated for combustion modification; (2) 2,707.83 €$_{2000}$/ t NOx abated for combustion modification with SCR; and (3) 1,490.69 €$_{2000}$/ t NOx abated for combustion modification with SNCR[3].

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[3] For both combustion modification with SCR and combustion modification with SNCR, the weight based on emissions are: (1) 3% of total emissions arises from combustion of fuel oil in other industrial combustion; (2) 6% of total emissions arises from combustion of coal in other industrial combustion; and (3) 91% of emissions arises from combustion of natural gas in industrial combustion and other sources.

SO_2

The following abatement measures have been considered as beyond BAU for this sector for SO_2 emissions:

- Low sulphur coal (0.6% S): this measure is applied to all solid fuels (i.e. coal, coke, petroleum coke and wood) for other industrial and public section combustion. This is described in the GAINS model (IIASA, 1998b) and an abatement efficiency of 50% on SO_2 emission levels has been assumed in the analysis, although the actual emission reductions is dependent on the quality and %S content of the fuel that is being replaced. Following the emissions-weighted average approach to calculate SO_2 abatement cost based on GAINS, annualised abatement cost is estimated to be 532.59 $€_{2000}$/ t SO_2[4].;

- Low sulphur oil (0.6%S): this measure is applied to all liquid fuels (i.e. burning oil, fuel oil, gas oil and lubricants) in other industrial combustion. An abatement efficiency of 50% on SO_2 emission levels has been assumed in the analysis, although the actual emission reductions is dependent on the quality and %S content of the fuel that is being replaced. The GAINS model provides an abatement cost of 625.76 $€_{2000}$/ t SO_2;

- Dry flue gas desulphurisation (FGD): this measure is applied to all fuels in other industrial sector combustions. The BBAU uptake rate is assumed to be 100%. Dry FGD systems pneumatically inject powdered sorbent directly in to the furnace, the economiser, or downstream ductwork. The dry waste product is removed using dust collection device such as a bag filter or ESP. Calcium and sodium based alkaline reagents and limestone are used. Dry scrubbers have significantly lower capital and annual costs than wet systems because they are simpler, demand less water and waste disposal is less complex. Dry injection systems also install easily and use less space, therefore they are good candidates for retrofit applications. An abatement efficiency of 80% has been applied. Annualised investment costs of 766.67 $€_{2011}$/ t NOx from AMEC (to be published) were used.; and

- Switch from coal to biomass in boilers: Capital investment cost of 357 $£_{2010}$ /kW for a biomass industrial boilers (DECC, 2011) and an abatement efficiency of 30% has been applied.

For dry FGD and switching from coal to biomass boiler, electricity generation capacity was estimated for combustion of all fuels in other industrial and public sector combustion. Because the NAEI did not provide fuel consumption for 2025 and 2030, the emissions and fuel consumption information from 2020 for these sources were used to project fuel consumption in 2025 and 2030. Using the estimated fuel consumption and gross calorific values from DUKES (DECC, 2012a), energy input (PJ and MWh) of these sources was estimated. Plant efficiencies of 86% to 89% (DECC, 2012b) and load factors of 85% (coal and fuel oil) and 6% (the remaining fuel types) were assumed. Combustion of fuels in other industrial combustion was assumed to be process heating, whereas the public sector combustion was assumed to be mixed. Therefore temperature factors of 100% and 60% were assumed for other industrial and public sector combustion, respectively. Based on these assumptions, capacity for electricity was estimated to be 26.2 GW and 25.4 GW in 2025 and 2030 for combustion of all fuels in other industrial and public sector combustion.

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[4] The weights based on emissions are: (1) 88% of total emissions arises from combustion of coal, coke and petroleum coke in other industrial combustion; (2) 12% of total emissions arises from combustion of coal in public sector combustion and other sources.

Dust

Electrostatic precipitator - stage 1 (ESP 1): two investment costs were developed for this measure as it is applied to (1) combustion of all solid and liquid fuels in other industrial, public sector and agriculture stationary combustion; and (2) combustion of natural gas in other industrial, public sector, agriculture stationary and miscellaneous industrial/commercial combustion. An abatement efficiency of 97% and 93% from the GAINS Model has been applied for PM_{10} and $PM_{2.5}$ emissions respectively. Similar to combustion modification, an emissions-weighted average approach was used to estimate PM abatement costs (2,654.78 $€_{2000}$/ t PM abated) and the total tonnes of PM_{10} emissions were used to calculate PM abatement costs for this study.

A3.4. Summary of measures and costs

Table A3.1 summarises the estimated cost of each abatement technology for the other combustion sector. The costs in the summary table are based on the average cost of each abatement technology. Table A3.2 presents the reduction efficiency of the abatement measures and the associated reduction in emissions.

Table A3.1 Summary of beyond BAU abatement measures for the Other Combustion sector for 2025 and 2030 [1]

Abatement measure	Future uptake of measure (%)		Operating life (years)	Capital Costs (£k, 2011 prices)		Annual operating costs (£k, 2011 prices)		Total annualised costs (£kpa, 2011 prices)	
	2025	2030		2025	2030	2025	2030	2025	2030
Combustion modification	85%	85%	N/A	N/A	N/A	N/A	N/A	44,404	44,371
Combustion modification + SCR	100%	100%	N/A	N/A	N/A	N/A	N/A	94,361	94,290
Combustion modification + SNCR	100%	100%	N/A	N/A	N/A	N/A	N/A	45,453	45,419
Low sulphur coal (0.6%S)	100%	100%	N/A	N/A	N/A	N/A	N/A	4,806	4,553
Low sulphur oil (0.6%S)	100%	100%	N/A	N/A	N/A	N/A	N/A	1,679	1,634
Dry FGD: sorbent (limestone) injection	89%	89%	N/A	N/A	N/A	N/A	N/A	11,276	15,109
Switch from coal to biomass boiler	100%	100%	20	251,774	234,113	87,457	81,322	105,172	97,795
ESP	100%	100%	N/A	N/A	N/A	N/A	N/A	13,599	13,451
ESP (Natural Gas)	100%	100%	N/A	N/A	N/A	N/A	N/A	1,525	1,536

Note 1: The costs presented here are the average costs for each abatement measure (in case a measure was given a range of costs). Where a cost per tonne of pollutant abated was applied in the analysis, no capital and operating costs are presented (i.e. N/A). A discount rate of 3.5% is considered in the analysis.

Table A3.2 Summary of beyond BAU abatement measures efficiency for the Other Combustion sector

Abatement measure	Emission reduction efficiency (%)						Reduction in 2025 emissions (kt)						Reduction in 2030 emissions (kt)					
	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3
Combustion modification	50%						22.1						22.1					
Combustion modification + SCR	80%						41.6						41.6					
Combustion modification + SNCR	40%						20.8						20.8					
Low sulphur coal (0.6%S)		50%						10.8						10.2				
Low sulphur oil (0.6%S)		50%						3.2						3.1				
Dry FGD: sorbent (limestone) injection		80%						16.9						16.0				
Switch from coal to biomass boiler		30%						5.1						4.8				
ESP			93%	97%					3.5	6.1					3.4	6.1		
ESP (Natural Gas)			93%	97%					0.7	0.7					0.7	0.7		

A3.5. References

1. AEAT (2009). Projected Emission Projections - The results and assumptions of the 2007 to 2020 air quality pollutant emission projections. A report of the National Atmospheric Emissions Inventory, March 2009.

2. AMEC (to be published). Final report. Collection and analysis of data to support the Commission in reporting in line with Article 73(2)(a) of Directive 2010/75/EU on industrial emissions on the need to control emissions from the combustion of fuels in installations with a total rated thermal input below 50MW. Study for the European Commission.

3. DECC (2012a). A.1 Estimated average calorific values of fuels 2010. http://www.decc.gov.uk/en/content/cms/statistics/energy_stats/source/cv/cv.aspx.

4. DECC (2012b). DECC 2050 Pathways Calculator. http://2050-calculator-tool-wiki.decc.gov.uk/pages/42

5. DECC (2012c). Bioenergy Strategy - Analytical Annex. URN: 12D/078. April 2012.

6. Entec (2008). Phase I of the impact assessment of the proposals for a revised IPPC Directive.

7. IIASA (1998a). Nitrogen oxides emissions, abatement technologies and related costs for Europe in the RAINS model database . http://www.iiasa.ac.at/%7Erains/reports/noxpap.pdf

8. IIASA (1998b). Sulfur emissions, abatement technologies and related costs for Europe in the RAINS model database. http://www.iiasa.ac.at/%7Erains/reports/so2-1.pdf

A4. Contents

A4 Autogenerators

A4.1. Sector profile

The NAEI includes two categories of autogenerators which are significant sources of emissions; coal fired or gas fired units. Autogenerators are units which are used to generate electricity onsite for use by industrial installations, data centres, hospitals, universities etc. Autogenertors may be used as an alternative to using electricity from the national grid where it is more cost effective, particularly in the case of combined heat and power plant, or where there is no grid connection available. Alternatively autogenerators may be required as an emergency backup for critical activities for use in the event of power cuts on the national grid.

The coal fired category is predominantly made up of the Lynemouth and Wilton power stations, which supply an aluminium and chemicals installation respectively. These coal fired autogenerators are similar to the coal fired power stations in the power sector, albeit with slightly smaller capacity. Gas fired autogenerators can be more varied, ranging in size from kW scale combustion engine generators to MW scale gas turbines. There are therefore similarities with the gas fired power stations, but also with smaller units covered in the other combustion sectors.

Autogenerators are a significant source of NOx and SO_2 emissions in the UK. The NAEI projections suggest that autogenerators would contribute to 6% of the UK's national NOx emissions in 2025 and 2030 (2% from coal and 4% from natural gas). The coal fired autogenerators would contribute to 9% of SO_2 emissions in 2025 and 2030.

A4.2. Business as usual policies and abatement measures

For the development of the NAEI, the coal fired autogenerators have been considered to be exempt from the Large Combustion Plant Directive (LCPD) and the Industrial Emissions Directive (IED)[1]. Therefore abatement measures which are standard in the power sector in order to meet the ELVs, namely FGD and SCR, are not installed in Lynemouth and Wilton.

For discussion on how the LCPD and the IED are affecting small-size combustion plants, please see the Other Combustion sector chapter.

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[1] Lynemouth has since been ruled to not be exempt from the LCPD. Rio Tinto Alcan closed the Lynemouth alumiunium smelter on 29 March 2012 (Rio Tinto, 2012). Talks on the sale of Lynmouth Power Station to be connected to the national grid are on-going as of March 2012. Future NAEI projections will need to be adjusted for this change.

A4.3. Beyond business as usual potential abatement measures

4.1.1 SO_2

The following measures have been considered for SO_2 emissions from autogenerators, which are discussed in detail in Power Station chapter. The same methodology to estimate abatement efficiency and investment costs developed in Power Station chapter has been used:

- Coal fired autogenerators:
    - Low sulphur coal (from UK average of 0.91% to 0.51%);
    - Closure and reopen combined cycle gas turbine (CCGT) (50% uptake)
    - Closure and reopen combined CCGT with selective catalytic reduction (SCR) (50% uptake);
    - Increased biomass co-firing (co-milling);
    - Increased biomass co-firing (direct injection);
    - Biomass conversion;
- Natural gas fired autogenerators:
    - Close existing CCGT and open renewable (non-thermal).

For all of these measures, the BAU uptake levels are assumed to be 0% and the BBAU uptake levels 100%.

4.1.2 NOx

The following measures have been considered for NOx emissions from autogenerators, which are discussed in detail in Power Station chapter. The same methodology to estimate abatement efficiency and investment costs developed in Power Station chapter has been used:

- Coal fired autogenerators:
    - Retrofit SCR;
    - Closure and reopen combined cycle gas turbine (CCGT) (50% uptake);
    - Closure and reopen combined CCGT with selective catalytic reduction (SCR) (50% uptake);
- Natural gas fired autogenerators:
    - SCR retrofit to CCGT (JEP) (75% uptake);

- Close existing CCGT and open renewable (non-thermal).

For all of these measures, the BAU uptake levels are assumed to be 0% and the BBAU uptake levels 100%, except for SCR retrofit to CCGT (JEP) measure where the BBAU uptake level is assumed to be 75%.

4.1.3 PM

The following measures have been considered for NOx emissions from autogenerators, which are discussed in detail in Other Combustion and Power Station chapters. The same methodology to estimate abatement efficiency and investment costs developed in Other Combustion and Power Station chapters has been used:

- Coal fired autogenerators:
    - ESP (from Other Combustion);
    - Closure and reopen combined cycle gas turbine (CCGT) (50% uptake) (from Power Station); and
    - Closure and reopen combined CCGT with selective catalytic reduction (SCR) (50% uptake) (from Power Station);
- Natural gas fired autogenerators:
    - Close existing CCGT and open renewable (non-thermal) (from Power Station);
    - ESP (from Other Combustion).

For all of these measures, the BAU uptake levels are assumed to be 0% and the BBAU uptake levels 100%. .

A4.4. Summary of measures and costs

Table A4.1 summarises the estimated cost of each abatement technology for the autogenerators sector. The costs in the summary table are based on the average cost of each abatement technology. Table A4.2 presents the reduction efficiency of the abatement measures and the associated reduction in emissions.

Table A4.1 Summary of beyond BAU abatement measures for the autogenerators sector for 2025 and 2030 [1]

Abatement measure	Future uptake of measure (%)		Operating life (years)	Capital Costs (£k, 2011 prices)		Annual operating costs (£k, 2011 prices)		Total annualised costs (£kpa, 2011 prices)	
	2025	2030		2025	2030	2025	2030	2025	2030
ESP (from other combustion)	100%	100%	N/A	N/A	N/A	N/A	N/A	739	739
Low sulphur coal (from UK average of 0.91% to UK average of 0.51%)	100%	100%	N/A	N/A	N/A	N/A	N/A	35,962	35,962
Retrofit SCR	100%	100%	15	58,664	58,664	5,509	5,509	10,603	10,603
Coal Closure and reopen CCGT (50% uptake)	100%	100%	20	309,466	309,466	39,424	39,424	61,199	61,199
Coal Closure and reopen CCGT with SCR (50% uptake)	100%	100%	20	361,011	361,011	41,350	41,350	66,751	66,751
Increased biomass co-firing (co-milling)	100%	100%	1	-	-	15,859	15,859	15,859	15,859
Increased biomass co-firing (direct injection)	100%	100%	15	144,804	144,804	15,859	15,859	28,431	28,431
Biomass conversion	100%	100%	20	397,670	397,670	15,859	15,859	43,839	43,839
SCR retrofit to CCGT (JEP) (75% uptake)	75%	75%	15	733,465	733,465	19,562	19,562	83,245	83,245
Close existing CCGT and open renewables (non-thermal)	100%	100%	25	8,629,358	8,629,358	-1,890,293	-1,890,293	-1,366,715	-1,366,715
ESP (from other combustion)	100%	100%	N/A	N/A	N/A	N/A	N/A	335	335

Note 1: The costs presented here are the average costs for each abatement measure (in case a measure was given a range of costs). N/A is not available: for example if total annualised cost is presented in source data without capital and operating costs presented separately, or if the total annualised costs are calculated from data based on cost per tonne of pollutant abated. A discount rate of 3.5% is considered in the analysis.

Table A4.2 Summary of beyond BAU abatement measures efficiency for the autogenerators sector

Abatement measure	Emission reduction efficiency (%)						Reduction in 2025 emissions (kt)						Reduction in 2030 emissions (kt)					
	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3
ESP (from other combustion)			93%	97%					0.2	0.3					0.2	0.3		
Low sulphur coal (from UK average of 0.91% to UK average of 0.51%)		44%						9.8						9.8				
Retrofit SCR	80%						5.8						5.8					
Coal Closure and reopen CCGT (50% uptake)	51%	100%	99%	99%			3.7	22.4	0.2	0.4			3.7	22.4	0.2	0.4		
Coal Closure and reopen CCGT with SCR (50% uptake)	90%	100%	99%	99%			6.6	22.4	0.2	0.4			6.6	22.4	0.2	0.4		
Increased biomass co-firing (co-milling)		100%						22.4						22.4				
Increased biomass co-firing (direct injection)		100%						22.4						22.4				
Biomass conversion		100%						22.4						22.4				
SCR retrofit to CCGT (JEP) (75% uptake)	80%						10.1						10.1					
Close existing CCGT and open renewables (non-thermal)	100%	100%	100%	100%			16.8	0.0	0.2	0.2			16.8	0.0	0.2	0.2		
ESP (from other combustion)			93%	97%					0.2	0.2					0.2	0.2		

A4.5. Reference

1. Rio Tinto (2012). Media Release. First quarter 2012 operations review. http://www.riotinto.com/documents/120417_First_quarter_2012_operations_review.pdf

A5. Contents

A5 Oil & Gas

A5.1. Sector profile

The oil and gas industry is a strategic industry for UK's economy. It still supplies over half of the UK energy needs and supports around 350,000 jobs. Over the last 45 years, around 40 billion barrels of oil equivalent have been extracted from the UK Continental Shelf (UKCS) and, although production has declined steadily for both fuels since 2000, it is forecasted that another 20 billion remain to be extracted (Oil & Gas UK, 2011).

The UK was the second largest gas and largest oil producer in the EU in 2011, and remains within the top 20 producers globally (DECC, 2012a).

5.1.1 Crude Oil Loading

UK oil production occurs predominantly under the seas surrounding the UK, where there is a network of 14,000 km of pipelines linking oil platforms and a large number of subsea installations (Oil & Gas UK, 2012). Accordingly, there are 195 offshore and 29 onshore oil fields operating in the UK, which in 2011 produced 48,571 million tonnes of crude oil (DECC, 2012a).

Crude oil is extracted from under the North Sea and transferred ashore either by pipeline or by shuttle tanker. Shuttle tankers are used for some fixed platforms and for Floating, Production, Storage and Offloading vessels (FPSOs). These are ships that function as production facilities.

The NAEI projections indicate that VOCs are the key emission for crude oil loading from onshore and offshore facilities, with a contribution to UK's total VOC emissions of approximately 5.3% in 2025 4.7% in 2030. These emissions can be generally classified as VOC loading or transit emissions:

- Loading emissions - these occur as the oil is loaded into a trading tanker, shuttle tanker, FPSO (floating, production, storage and offloading) storage tanks (offshore loading) or during loading on an onshore oil reception terminal (onshore loading). Emissions occur from the mast riser or high jet vents as the vessel is being loaded with crude oil. Loading emissions vary with crude oil properties, temperature and environmental conditions.

- Transit emissions: A small quantity of VOC emissions may occur whilst a vessel is en-route to or from a crude oil loading terminal. Cargo temperature, sea and air temperature, sea conditions, cargo vapour pressure and vessel stability all affect the quantity of vapour generated.

More VOC emissions occur during crude oil loading from onshore facilities (2.3% and 2.0% of total UK VOC emissions in 2025 and 2030, respectively) than from offshore facilities (1.9% and 1.6% of total UK VOC emissions in 2025 and 2030, respectively). No other types of emissions are forecast in the crude oil loading sector.

During discussions with the Oil & Gas UK trade association and BERR[1] it was highlighted that offshore VOC emissions occur predominantly during the loading of shuttle tankers, either directly from the fixed oil platforms or from Floating, Production, Storage and Offloading (FPSOs) vessels[2]. For the purposes of this study it was assumed that all offshore VOC emissions occur during the loading of shuttle tankers.

5.1.2 Gas Combustion

The extraction, stabilisation and export of hydrocarbons involve several gas combustion processes that release atmospheric emissions. Natural gas is consumed at the production sites to provide electrical power and to drive compressors and pumps.

In 2011, the 145 offshore gas platforms and the 21 onshore gas fields operating in the UK produced 526,030 GWh of gas. Producers used 10% of this gas on-site for drilling, production and pumping operations (DECC, 2012b).

The NAEI projections indicate that on-site gas combustion in oil and gas production is a key source of UK NOx emissions (approximately 5% for both 2025 and 2030). There are emissions of other pollutants such as SO2, particulate matter (PM2.5 & PM10) and VOC, but these are considered insignificant (<0.25%), hence abatement measures for these pollutants have not been further investigated.

5.1.3 Flaring

In oil and gas production facilities the excess of gas is flared for safety reasons and during well testing, releasing atmospheric emissions. Flare systems are used throughout the UK oil and gas industry although this practice is expected to decrease further in the future in order to enable the operators to sell more of the extracting fuels. NAEI projections reveal that flaring is a significant source of VOC (1.1% in 2025 and 1.0% in 2030) and PM2.5 (1.2% in 2025 and 1.1% in 2030) emissions in the UK.

5.1.4 Natural gas supply

Gas leakage from natural gas supply is a significant source of VOC emissions in the UK: the NAEI projects that it will contribute to 4.0% and 3.4% of the total UK VOC emissions in 2025 and 2030, respectively.

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[1] Communication on the 3rd June 2008

[2] In discussion with BERR and an offshore operator (June 2008) it was mentioned that only a few (3 – 4) fixed oil platforms have storage facilities available where crude oil can be stored temporarily before it is loaded on shuttle tankers or transported via pipelines.

A5.2. Business as usual policies and abatement measures

5.2.1 Crude Oil Loading

Crude oil loading activity is regulated by a range of environmental directives and protocols that are aiming to reduce pollutant emissions and the risk of accidents. Key European and international legislation affecting this activity include (Oil & Gas UK, 2012a and 2012b):

- MARPOL 73/78 Annex VI – Prevention of Air Pollution from Ships, which seeks to control NOx, SOx, and VOCs and requires ships to be issued with an International Air Pollution Certificate following survey. In the UK, this has been transposed with the UK Merchant Shipping Regulations 2008 and Amendment 2010. All crude oil tankers are required to have on board and implement a VOC Management Plan approved by the administration; and

- Integrated Pollution Prevention and Control (IPCC) Directive and Large Combustion Plant (LCP) Directive, which were replaced by the Industrial Emissions Directive (IED). In the UK, this has been transposed with Offshore Combustion Installations (Prevention and Control of Pollution) Regulations 2001 and its amendment 2007. VOC emissions from cargo loading at onshore terminals are covered by the terminal's IPPC permit.

During discussion with the Oil & Gas UK trade association and an offshore oil and gas operator in 2008 it was indicated that the UK sector has not implemented to a great extent abatement measures and techniques e.g. VOC recovery units (VRU) to reduce their VOC emissions under current BAU commitments, particularly from offshore activities. A VOC Management Plan has become a requirement since 2010 but there are no performance criteria for VOC management. For the analysis, it is assumed that the current uptake rate of VRU is 0%.

The Oil & Gas UK sustainable development report (2007) indicates that VOC emissions of the sector have decreased by about 50% from 2001 to 2005 (from about 200,000 tonnes to about 100,000 tonnes). A report that the Oil & Gas UK produced in 2003 (UKOOA, 2003)[3] presented a number of abatement techniques and associated costs for VOC emissions control. The report calculated a cost effective range for VOC recovery units (VRU - £1,700 to 3,900 ton per VOC abated) and indicated that 4 out of all 23 (about 17%) onshore and offshore facilities in the UKCS had installed this technique already.

5.2.2 Gas Combustion

Gas combustion activity is regulated by a range of environmental directives and protocols that are aiming to reduce pollutant emissions and the risk of accidents. Key European and international legislation affecting this activity include (Oil & Gas UK, 2012c) are Integrated Pollution Prevention and Control (IPCC) Directive and Large Combustion Plant (LCP) Directive, which were replaced by the Industrial Emissions Directive (IED). These cover atmospheric emissions from combustion installations located on offshore oil and gas platforms where an item of combustion plant on its own, or together with any other combustion plant installed on a platform, has a rated

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[3] This report has never been published and it is not available on the public domain

thermal input exceeding 50 MW(th). In the UK, this has been transposed with Offshore Combustion Installations (Prevention and Control of Pollution) Regulations 2001 and its amendment 2007.

The IPPC Directive applied to existing installations from October 2007 and a revised guidance note has been developed by DECC (2009) on offshore combustion installations. The guidance note explains that IPPC permit conditions are based on the use of Best Available Techniques (BAT) and operators requiring a permit should assess polluting releases and the identification of BAT. It also adds that the operators of new combustion installations are strongly recommended to install BAT. Annex II of the guidance note presents BAT to be considered for offshore combustion installations, including gas turbines, reciprocating engines, heaters & boilers (including inert gas generators), waste heat recovery and monitoring and reporting. For gas turbines the guidance note (Annex II, page 42-44) describes the Dry Low NOx (DLN) or Dry Low Emissions (DLE) abatement measure for abatement of NOx emissions and summarises that "*For the purpose of these Regulations, the Department therefore considers that DLN systems would normally represent BAT when selecting equipment for new facilities. However, for some new facilities, and the vast majority of existing facilities, DLN may not necessarily be appropriate. It is therefore the responsibility of the applicant to justify the chosen solution*". The DLN technique is also quoted in the LCP BREF document (EC, 2006) for offshore combustion installations, among other techniques, that can be applied to reduce NOx emissions.

It is not yet clear whether any additional NOx abatement techniques are required under BAU policies for existing (plants operating and requiring a permit before 30th October 2007) offshore combustion installations, based on the details included in Annex II of the guidance note. As it is unclear what the current performance of existing offshore installations in relation to BAU IPPC commitments is likely to be, it was assumed that current BAU commitments would not require further abatement of NOx emissions and the fitting of DLN or other relevant abatement techniques.

5.2.3 Flaring

Flaring is regulated a range of environmental legislation directives that are aiming to reduce pollutant emissions and the risk of accidents. Key European legislation affecting this activity include (Oil & Gas UK, 2012d) is Petroleum Act 1998, Petroleum Licensing (Exploration and Production) (Seaward and Landward Areas) Regulations 2004 and Petroleum Licensing (Production) (Seaward Areas) Regulations 2008. It aims to conserve gas by avoiding unnecessary wastage during the production. Where a field is flaring > 50 tonnes per day the flare level will be reviewed by DECC and a flare consent issued annually. Where a field is flaring < 50 tonnes per day, a longer term flare consent may be applied for/issued. Licensee is not to flare any gas from the licensed area or use gas for gas lift except with written consent;

DECC has an objective to reduce non-safety related flaring by 5% per year (Oil & Gas UK, 2012d). It has been left to individual Field Teams to decide how to meet that objective. The Southern North Sea Field Team have decided to meet the objective by an across the board reduction in flare consents. The Aberdeen based staff have decided to take a different approach, and are assessing proposals on a case-by-case basis to achieve the same overall reduction.

5.2.4 Natural gas supply

Following societal concern about the risks of gas mains failure from about 91,000 km of iron mains within 30m of property ('at risk'), Health and Safety Executive (HSE, 2012) published its first enforcement policy for the replacement of iron gas mains for the period 2002 – 2007. Then it reviewed the policy and updated it for the period 2006 – 2012 in 2005. HSE considered it realistic and practical for Transco plc, who owned and operated all the gas distribution networks, to speed up its rate of mains replacement so that it was in position to complete the replacement of all the remaining 'at risk' iron mains within 30 years. It is assumed that emissions projections for 2025 and 2030 take into account the likely VOC abatement due to this project.

Other measures implemented to reduce leakage from gas pipes include treatment of North Sea gas with monoethylene glycol in order to reduce leakages from joints and modifying the gas pressure in the gas mains according to the demand.

A5.3. Beyond business as usual potential abatement measures

This subsection describes the abatement measures that have been considered for reductions of key emissions (discussed in Section A5.1) from the oil and gas sector.

5.3.1 Crude Oil Loading

VOC

Three measures were considered to address VOC emissions from crude oil loading at onshore and offshore facilities: (1) VOC recovery unit (VRU); (2) modification to floating production; and (3) modification to shuttle tankers.

A VOC recovery unit (VRU) is generally applied to both onshore and offshore VOC emissions. An abatement efficiency of 70% has been assumed in the analysis (UKOOA, 2003). The UKOOA report suggested that recovery of VOCs can be done through condensation, absorption onto a solvent, adsorption onto carbon and membrane separation. BBAU uptake rate was assumed to be 100% for 2025 and 2030. UKOOA (2003) suggested the annualised cost to range between 1,700 and 3,900 £$_{2003}$/tonne of VOC reduced and an average value of 2,800 £$_{2003}$/tonne of VOC reduced was used for this analysis.

Modification to floating production and modification to shuttle tankers are applied to offshore VOC emissions. An abatement efficiency of 60% has been assumed in the analysis for both measures (AEA, 2001). There are a number of technologies being trialled in the offshore oil industry to reduce emissions of VOC from offshore loading of crude oil to shuttle tankers including (1) absorption of VOC in crude oil; (2) condensation of VOC using refrigeration and pressurisation and use as fuel; and (3) vapour balancing between floating production, storage and off-take (FPSO) vessels and shuttle tanker.

For modification to floating production, BBAU uptake rate was assumed to be 100% for 2025 and 2030. AEA (2001) suggested the annualised cost to range between 400 and 4,000 $€_{2001}$/tonne of VOC reduced and an average value of 2,200 $€_{2001}$/tonne of VOC reduced was used for this analysis.

For modification to shuttle tankers, BBAU uptake rate is assumed to be 83% considering the BAU uptake rate of 17%. AEA (2001) suggested the annualised cost to range between 1,000 and 5,000 $€_{2001}$/tonne of VOC reduced and an average value of 3,000 $€_{2001}$/tonne of VOC reduced was used for this analysis.

5.3.2 Gas Combustion

NOx

Dry low NOx (DLN) was considered to reduce NOx emissions from gas combustion activities from oil and gas production. It 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. DLN abatement technique is applicable to new gas turbines, but it may not be always applicable for retrofitting existing gas turbines as it is not mature yet for “dual fuel” turbines and it requires a significant upgrade of the controls and hence additional space which may not be available (EC, 2006). Abatement efficiency of 86% on NOx emission levels (EC, 2006, p 457) and BBAU uptake rate of 90% was assumed considering that some 10% of boilers would be too small to install DLN. The LCP BREF suggested the annualised cost to range between 3 and 125 $€_{2006}$/kg of NOx reduced and an average value of 64 $€_{2001}$/kg of NOx reduced was used for this analysis.

5.3.3 Flaring

VOC

Improved ignition system on flares was considered to reduce VOC emissions from flaring activities in oil and gas production. Abatement efficiency of 62% on NOx emission levels (IIASA GAINS model) and BBAU uptake rate of 100% was assumed (0% for BAU). Annualised cost of 28,998 $€_{2005}$/tonne of VOC reduced from the GAINS model was used for this analysis.

PM

No measures for PM10 from natural gas flaring have been developed. One way to reduce PM emissions from flaring is to reduce the flaring by capturing the gas and selling it. However, this volume of gas sold to consumers will be combusted eventually and would lead to associated PM emissions. In addition, traditional techniques to reduce PM emissions from natural gas combustion such as the use of filters are not easily applicable to flaring where the combustion is not very well controlled.

5.3.4 Natural Gas Supply

VOC

One potential option for additional abatement of VOC emissions would be a further acceleration of the mains replacement programme. However, the HSE (2012) has considered the option of a 25 year programme and concluded that it is not practically achievable due to the lack of trained personnel and problems arising in replacing large-scale pipeworks in urban area.

No other additional measures beyond BAU level have been identified for this activity based on literature review.

A5.4. Summary of measures and costs

Table 5.1 summarises the estimated cost of each abatement technology for the crude oil loading, gas combustion and flaring from the oil and gas production sector. The costs in the summary table are based on the average cost of each abatement technology.

Table 5.2 presents the reduction efficiency of the abatement measures and the associated reduction in emissions.

Table 5.1 Summary of beyond BAU abatement measures for the oil & gas sector for 2025 and 2030 [1]

Abatement measure	Future uptake of measure (%)		Operating life (years)	Capital Costs (£k, 2011 prices)		Annual operating costs (£k, 2011 prices)		Total annualised costs (£kpa, 2011 prices)	
	2025	2030		2025	2030	2025	2030	2025	2030
Vapour recovery unit (onshore)	100%	100%	N/A	N/A	N/A	N/A	N/A	38,869	34,899
Vapour recovery unit (offshore)	100%	100%	N/A	N/A	N/A	N/A	N/A	31,314	28,116
Modification to floating production	100%	100%	N/A	N/A	N/A	N/A	N/A	13,711	12,311
Modification to shuttle tankers	83%	83%	N/A	N/A	N/A	N/A	N/A	15,445	13,868
Dry Low NOx	90%	90%	N/A	N/A	N/A	N/A	N/A	926,634	831,993

Note 1: The costs presented here are the average costs for each abatement measure (in case a measure was given a range of costs). In this sector, a cost per tonne of pollutant abated was applied in the analysis, therefore no capital and operating costs are presented (i.e. N/A). A discount rate of 3.5% is considered in the analysis.

Table 5.2 Summary of beyond BAU abatement measures efficiency for the oil & gas sector

Abatement measure	Emission reduction efficiency (%)						Reduction in 2025 emissions (kt)						Reduction in 2030 emissions (kt)					
	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3
Vapour recovery unit (onshore)					70.0%						10.70						9.61	
Vapour recovery unit (offshore)					70.0%						8.62						7.74	
Modification to floating production					60.0%						7.39						6.63	
Modification to shuttle tankers					49.6%[1]						6.10						5.48	
Dry Low NOx	86.0%						17.89						16.06					
Improved ignition system on flares					62.0%						4.70						4.22	

Note 1: For modification to shuttle tankers, emission reduction efficiency was adjusted from 60% to 49.6% to reflect 17% BAU uptake rate (49.6% = 60% * 17%).

A5.5. References

1. AEA (2001) "Measures to Reduce Emissions of VOCs during Loading and Unloading of Ships in the EU" http://ec.europa.eu/environment/air/pdf/vocloading.pdf

2. DECC (2009) Offshore Combustion Installations (Prevention and Control of Pollution) Regulations 2001 (As Amended) (SI 2001 No. 1091). Guidance Note. Edition 3, Version 2 http://og.decc.gov.uk/en/olgs/cms/environment/leg_guidance/ppc/guidance/guidance.aspx

3. DECC (2012a) “UK production data” Retrieved on 30/07/2012 from http://og.decc.gov.uk/en/olgs/cms/data_maps/field_data/uk_production/uk_production.aspx

4. DECC (2012b) “Digest of United Kingdom energy statistics (DUKES) for 2012: chapters 3 and 4” http://www.decc.gov.uk/en/content/cms/statistics/energy_stats/source/

5. European Commission (2006) “Reference document on BAT for Large Combustion Plants” http://eippcb.jrc.es/reference/BREF/lcp_bref_0706.pdf

6. HSE (2012). Enforcement Policy for the replacement of iron gas mains 2006 - 2013 - December 2005. http://www.hse.gov.uk/gas/supply/mainsreplacement/irongasmain.htm

7. IIASA (2006). The Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model for Europe, accessed from http://gains.iiasa.ac.at/models/index.html

8. Oil & Gas UK (2011) “Economic Report 2011” http://www.oilandgasuk.co.uk/economic_report/production.cfm

9. Oil & Gas UK (2012a) “Atmospheric Emissions – Process Venting and VOC Emissions from Offshore Loading” http://www.ukooaenvironmentallegislation.co.uk/contents/Topic_Files/Offshore/Venting.htm

10. Oil & Gas UK (2012b) “Atmospheric Emissions - Vapour Emissions from Crude Oil Offloading in Terminals and Harbours” http://www.ukooaenvironmentallegislation.co.uk/contents/Topic_Files/Offshore/VOC.htm

11. Oil & Gas UK (2012c) “Atmospheric Emissions - Power Generation” http://www.ukooaenvironmentallegislation.co.uk/contents/Topic_Files/Offshore/Power_generation.htm

12. Oil & Gas UK (2012d) “Atmospheric Emission – Flaring” http://www.ukooaenvironmentallegislation.co.uk/contents/Topic_Files/Offshore/Flaring.html

13. UKOOA (2003) “Volatile organic compounds mitigation and abatement costs”

A6. Contents

A6 Petroleum Refineries

A6.1. Sector profile

There are seven major crude oil refineries operating in the UK (4 in England, 2 in Wales and 1 in Scotland), situated around the coast for ease of crude tanker access (UKPIA, 2012). Petroplus Teeside closed in 2009 and refining operations in Petroleus Coryton ceased in June 2012 due to Petroleus entering into Administration in January 2012. Onwards distribution is achieved via an extensive pipeline system plus road, rail and sea transport.

UK refinery throughput was under 75 million tonnes in 2011 and utilisation rate was 80% in 2011 (UKPIA, 2012). The UK's crude feedstock is primarily low sulphur crude from the North Sea (51% from Norway and 29% from UK Continental Shelf), although in recent years there has been an increasing diversification trend and the proportion of imported crude out of total crude feedstock has increased steadily. Crude oil from Africa accounts for 8%, followed by Russia and the Middle East account at 5% and other regions at 7%. The majority of oil products processed at UK refineries (64%) are consumed in the UK market, and gas oil/diesel and petrol make up the majority of products.

The NAEI projections indicate that fuel combustion in petroleum refineries is a significant source of NOx (6%), SO_2 (22%), PM_{10} (2%) and $PM_{2.5}$ (1%) in the UK. Refinery processes require a lot of energy and typically more than 60% of refinery air emissions are related to the production of energy for the various processes (EC, 2012). In particular, refineries make a significant contribution to the UK's total SO_2 emissions e.g. combustion of fuel oil (14% in 2025 and 15% in 2030) and petroleum coke (8% in 2025 and 2030). Process emissions from the refining process, tankage and drainage are also a significant source of VOCs (4% in 2025 and 2030).

A6.2. Business as usual policies and abatement measures

Under BAU policies the petroleum refinery sector is required to meet permit conditions at an installation level under IPPC commitments and is also subject to the Large Combustion Plant (LCP) Directive which sets minimum emission limit values for SO_2, NOx and dust levels from solid, liquid and gaseous fuels. The IPPC permits for the refinery sector were issued late 2007/early 2008; in many cases these permits included over 40 improvement conditions that the operators are required to meet by the end of 2015 (EA, 2008). With the IED replacing the IPPC and LCP Directives, petroleum refineries under the BAU scenario will need to be in compliance with the IED (although the implications of the IED for the sector are uncertain as further work is currently ongoing). Furthermore, the operators may have to do more to meet the requirements of the Birds and Habitats Directives and the Control of Major Accident Hazards (COMAH) Regulations 1996 (which bring the Seveso II Directive into UK law).

NOx

In terms of NOx emissions and abatement measures, we have maintained the assumptions from earlier versions of the MPMD that Low and Ultra Low NOx burners will be a BAU technique with 100% uptake by 2025 and 2030. SCR and SNCR are not considered as BAU measures and were considered as beyond BAU measures when the sector was issued the IPPC permits in late 2007/early 2008.

SO_2

With declining crude oil reserves and production in the North Sea, UK refineries have been processing other crude oils with higher sulphur content. The refinery operators are aware of the likely increase in SO_2 emissions from processing higher sulphur crude oils and investment to increase sulphur recovery is planned (UKPIA, 2012).

Entec (2008) suggested that the refinery sector has undertaken trials over the following 2 years for applying deSOx catalysts in catalytic cracking units to reduce SO_2 emissions by transferring the sulphur so that it can be removed by existing amine treatment units. This technique is most likely to be fitted across the sector as it is one of the BATs suggested by Environment Agency (2009). Additionally, IPPC permits of the petroleum refinery operators obtained by AMEC indicate that sulphur recovery units (SRUs) are generally required to be upgraded to achieve an efficiency of 99.5% as an improvement condition for most operators in the near future; this efficiency can be achieved by using a 3-stage Claus sulphur recovery unit with a tail gas treatment unit. For the purposes of this study, we have maintained the assumptions from earlier versions of the MPMD that deSOx catalysts and SRU improvements are BAU abatement measures with an uptake of 100% by 2025 and 2030. These abatement measures will also enable the sector to use sourer crudes in the future once the North Sea sweet crudes become too expensive to use. It has also been assumed that amine treatment units and sulphur recovery units (100% BAU uptake) have been taken into account for the NAEI emission projections.

Dust

For dust emissions ESPs have been considered as a BAU measure with an uptake of 100% as it has also been a requirement included in IPPC permits.

VOC

Under the improvement conditions in the IPPC permits for the refinery sector, operators are required to achieve reductions in VOCs by fitting vapour recovery systems, double seals on tanks, etc. These measures are required in order to meet the requirements of the Petrol Vapour Recovery I Regulations, but also to ensure the protection of the worker under the H&S Act 1974. Most reductions can be achieved by good housekeeping and by establishing a programme for the prevention, detection and control of fugitive emissions (Leak Detection and Repair - LDAR). LDAR programme forms one of the improvement conditions in IPPC Permits for refineries and has been assumed to be a standard practice for all refineries by the years 2025 and 2030; therefore no BBAU measures have been considered for this study for VOCs.

A6.3. Beyond business as usual potential abatement measures

1.3.1 Combustion of fuels

NOx

Selective catalytic reduction (SCR) and selective non-catalytic reduction (SNCR) were considered as BBAU measures. 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). Application of SNCR to existing installations is simpler compared to SCR and space requirements are mainly related to NH_3 storage. However, SCR offers higher NOx removal efficiencies which may be required where permit conditions are tight. Based on the latest available draft (v.2) BREF document for refineries (EC, 2012), both SCR and SNCR are applicable to heaters, boilers, gas turbines (i.e. combustion processes) and fluid catalytic cracking units (FCCUs).

Capital and operating costs for SCR and SNCR were drawn from the draft (v.2) BREF document (EC, 2012). Because some of these costs were in terms of flue gas flow rates, total waste flow rates were calculated for fuel oil and OPG. For OPG, a default flue gas specific volume factor of 283 Nm^3/GJ was assumed. For fuel oil, a default flue gas specific volume factor of 300 Nm^3/GJ and a gross calorific value of 43.3 GJ/tonne were assumed. Based on these assumptions, waste gas flow from combustion of fuel oil and OPG was estimated to be 5.61million Nm^3/hour in 2025 and 5.62million Nm^3/hour in 2025 (the small difference arises from an increase in NOx emissions from combustion of fuel oil from 2025 to 2030), For both SCR and SNCR, BAU uptake level was assumed to be 0% and the BBAU uptake level was assumed to be 100% for both 2025 and 2030.

For SCR applied to combustion of fuel oil and OPG, an abatement efficiency of 86% on NOx emission levels has been considered in the analysis (EC, 2012, p.513). Investment and operation costs were drawn from several examples of SCR installation and the analysis used average values from these cases in draft (v.2) BREF document (EC, 2012, Table 4.83). For SCR applied to combustion of petroleum coke, the same abatement efficiency of 86% was assumed and investment costs were assumed to be average values from three examples from the draft (v.2) BREF document where SCR applied to fluid catalytic cracking (FCC) units (EC, 2012, Table 4.16).

For SNCR applied to all fuels, an abatement efficiency of 47.5% (average taken from a range of 25 – 70%) was assumed and investment costs were assumed to be average values from five examples from the draft (v.2) BREF document was considered in the analysis (EC, 2012, Table 4.82).

SO_2 and Dust

Switching from fuel oil to natural gas and wet scrubbers applied to combustion of petroleum coke were considered for reducing SO_2 and dust emissions.

For switching to natural gas, all the petroleum refinery operators are assumed to have access to a natural gas supply by 2025 and 2030 to burn as fuel. An abatement efficiency of 100% on SO_2, $PM_{2.5}$ and PM_{10} emissions levels has been assumed in the analysis from the amount of fuel that has switched.

There are two types of wet scrubbing typically used for FCC units: (1) sodium or magnesium-based non-regenerative system using packed towers, plate towers, spray chambers or Venturi systems; and (2) conventional scrubbing with a regenerative process. For our analysis, the abatement efficiency and investment costs were based on general examples from the draft (v.2) BREF documents. An abatement efficiency of 97.5% has been assumed for SO_2 emission levels and 90% for $PM_{2.5}$ and PM_{10} emissions (EC, 2012). NOx emissions can be reduced by up to 70% if an extra treatment tower is applied to oxidise the NO to NO_2, but this was not considered for this study. Investment costs of 25 – 60 $\$_{2009}$ and operating costs of 5 – 6 $\$_{2009}$ were based on a case of a wet gas scrubber application applied to a FCC with a throughput of 2.4 Mt/yr from the draft (v.2) BREF document (Table 4.28).

A6.4. Summary of measures and costs

Table A6.1 summarises the estimated cost of each abatement technology for the refining sector. The costs in the summary table are based on the average cost of each abatement technology.

Table A6.2 presents the reduction efficiency of the abatement measures and the associated reduction in emissions.

Table A6.1 Summary of beyond BAU abatement measures for the Petroleum Refineries sector for 2025 and 2030 [1]

Abatement measure	Future uptake of measure (%)		Operating life (years)	Capital Costs (£k, 2011 prices)		Annual operating costs (£k, 2011 prices)		Total annualised costs (£kpa, 2011 prices)	
	2025	2030		2025	2030	2025	2030	2025	2030
SCR for fuel oil & OPG combustion	100%	100%	15	178,812	179,173	781	781	16,306	16,338
SCR for petroleum coke combustion	100%	100%	N/A	N/A	N/A	N/A	N/A	10,557	10,675
SNCR	100%	100%	N/A	N/A	N/A	N/A	N/A	22,838	22,940
Switching from fuel oil to natural gas	58%	58%	N/A	N/A	N/A	N/A	N/A	227,933	230,485
Wet scrubber	100%	100%	15	34,670	34,670	4,487	4,487	7,497	7,497

Note 1: The costs presented here are the average costs for each abatement measure (in case a measure was given a range of costs). In cases a cost per tonne of pollutant abated was applied in the analysis (i.e. SCR for petroleum coke combustion, SNCR and Switching from fuel oil to natural gas, no capital and operating costs are presented (i.e. N/A). A discount rate of 3.5% is considered in the analysis.

Table A6.2 Summary of beyond BAU abatement measures efficiency for the Petroleum Refineries sector

Abatement measure	Emission reduction efficiency (%)						Reduction in 2025 emissions (kt)						Reduction in 2030 emissions (kt)					
	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3
SCR for fuel oil & OPG combustion	86%						15.81						15.84					
SCR for petroleum coke combustion	86%						5.72						5.78					
SNCR	47.5%						11.89						11.94					
Switching from fuel oil to natural gas		58%	58%	58%				19.7	0.23	0.36				19.9	0.24	0.36		
Wet scrubber		97.5%	90%	90%				18.6	0.21	0.81				18.2	0.21	0.81		

A6.5. References

1. Environment Agency (2008). IPPC and refineries: England and Wales. Presentation. Rory Caughlin, Technical Advisor, Environment Agency. U.K.

2. Environment Agency (2009). How to comply with your environmental permit. Additional guidance for: Gasification, Liquefaction and Refining Installations (EPR 1.02). http://publications.environment-agency.gov.uk/PDF/GEHO0209BPIW-E-E.pdf

3. European Commission (2012). Best Available Techniques (BAT) Reference Document for the Refining of mineral oil and gas. Draft 2 (March 2012).

4. United Kingdom Petroleum Industry Association (UKPIA) (2012) UKPIA Statistical review 2012. http://www.ukpia.com/Libraries/Download/Stats_review_2012.sflb.ashx

A7. Contents

A7. Iron & Steel

A7.1 Sector profile

7.1.1 Integrated iron and steel production

The UK iron and steel industry has reported a total crude steel production in 2011 of 9.5 Mt (UK steel, 2011). Steel produced by the basic oxygen steelmaking method at integrated steelworks accounted for 73% (6.9 Mt) of the total production and experienced a decrease of 5% on the previous year. This is mainly due to the mothballing of the export-orientated Teesside integrated steelwork by Tata Steel from February 2010. This plant was sold to the Thai company SSI, who restarted the blast furnace in April 2012. Excluding Teesside's contribution, UK basic oxygen steel production only dropped1% compared to 2010 (UK steel, 2011).

Despite of the sale of the Teesside plant, Tata Steel Europe (former Corus) continues to be the dominant company of the iron & steel integrated sector, as it owns the remaining two integrated steel works located in the UK, at Port Talbot and Scunthorpe. These have a production capacity of 4.9 and 4.5 million tonnes respectively and the company has announced it is investing in productivity improvement projects. A rebuild of a blast furnace at Port Talbot is planned, to increase the hot metal capacity by 0.4 million tonnes and reduce the cost of production (Tata Steel, 2011).

As downstream processing (rolling, coiling etc) is not a significant contributor of NOx, SOx, PM or VOC neither in the steel sector nor in the UK as a whole, this investigation has focused on the three integrated steelworks facilities. Emissions occurring from EAF process and foundries are described separately in the following chapters.

Each site operates the same basic process that consists of five distinct stages. These are:

1. Coke making. The majority of the imported energy into the iron and steel process is in the form of coal, which is converted into coke prior to being used in the blast furnace.

2. Sintering, in which the iron ore is roasted in preparation for converting to iron. An alternative to sintering is pelletisation, but there are no pelletisation plants in operation in the UK.

3. Iron making, in which the sintered ore, limestone, coke and other fuels are chemically reacted to reduce the iron ore to a crude metal called pig iron, which contains approximately 4% carbon, in a Blast Furnace.

4. Steel making and casting, in which the conversion of iron to steel is carried out by the basic oxygen steel making process (BOS) where the carbon level is reduced to approximately 1% and other remaining impurities removed by injecting oxygen and other gases through the iron, and the liquid steel cast into a solid for further processing or sale.

5. Hot Rolling, Forming, Cold Rolling and further processing, in which the output from the steel making is reheated, shaped and treated to give a wide range of finished products such as rods, bars, plate, sections, coil and tube.

The majority of UK coke production is linked to the main integrated iron and steel works, this section also considers independent coke ovens as the methods are assumed to be the same.

The primary processes use large quantities of raw material, hot or molten intermediate products and produce large amounts of partially combusted secondary gases and partially spent fuel gases with varying calorific values. At Scunthorpe (Corus, 2008), all process arising gases (coke oven gas (COG), basic oxygen steelmaking gas (BOSG) and blast furnace gas (BFG)) are blended in order to produce a mixed enhanced gas (MEG) with a steady calorific value. Natural gas is occasionally used at Scunthorpe to create synthetic COG, which is mixed into the MEG stream. It is not burnt alone as a fuel at Scunthorpe. Process gases, individually and as MEG, are distributed around the entire Scunthorpe site and combusted in a range of plants (e.g. power station, reheat furnace, coke oven underfiring etc.).

MEG is not produced at Port Talbot, but COG and BFG are used as fuels across both plants. BOSG is collected since the commissioning of the BOS gas recovery plant in early 2010 (Tata Steel, 2011). Very little process gas is currently flared at either of the two sites and plans are being developed at both Scunthorpe and Port Talbot to upgrade existing on-site power generation facilities in order to optimise gas usage. This is particularly pertinent at these sites where a combination of; increased steelmaking capacity (both sites), rationalisation of downstream rolling operations and reheating requirements (Scunthorpe), and installation of the BOSG collection scheme (Port Talbot) would otherwise result in a ‘surplus’ of process gas which would have to be flared.

The NAEI projections indicate that sulphur dioxide (SO_2) is one of the most significant emissions for the iron & steel production, with a contribution to UK SO_2 emissions of approximately 17% in 2025 and 2030. The main sources of SO_2 emissions in an integrated steelwork are sinter production (6.1%), combustion of COG across the processes (3.7%), coke production (2.9%) and fuel combustion (2.3%).

In addition, integrated iron & steel is also responsible for approximately 6% of UK’s oxides of nitrogen (NOx) emissions in 2025 and 2030, which primarily occur as a result of sinter production, combustion and coke production.

Dust emissions are also relevant and account for around 5% of both PM_{10} and $PM_{2.5}$ total emissions in the UK. Basic oxygen furnaces, stockpiles and sinter production (iron) are key sources of both categories of particulate matter. Emissions also occur during coke production and at blast furnaces, although these are a much lower contributor.

7.1.2 Electric Arc Furnaces

Electric Arc Furnaces (EAFs) can be defined as cylindrical refractory lined vessels with (usually) three carbon electrodes that can be raised or lowered through a removable furnace roof (DEFRA, 2002). EAF, together with the basic oxygen process, is one of the two modern ways of making steel. Instead of using hot metal they are charged with “cold” material, usually steel scrap. Once the ferrous material is charged into the furnace from an overhead crane, the electrodes are lowered and an electric current is passed through them to form an arc that melts the metallic charge. When the melting cycle is complete, the vessel is tilted and the molten steel poured. The process also generates slag (a by-product consisting of contaminants from the scrap steel) (UK Steel, 2012).

In the UK, EAFs making special quality steels (steels alloyed with other metals) are located in Sheffield and Rotherham (in Yorkshire), while there are EAFs making ordinary quality steels at Sheerness on the Thames estuary in Kent and Cardiff in South Wales (UK Steel, 2012). The EAF process route in the UK produced 2.5 Mt in 2011, 6% higher than in 2010, and accounted for 26% of total crude steel production (UK Steel, 2011).

The key emissions to consider from EAF are $PM_{2.5}$, which accounts for 0.3% of the UK’s $PM_{2.5}$ emissions in 2030. Particulate emissions mainly occur during the following operations: charging the scrap, melting and refining, tapping steel, casting operations, and dumping slag (DEFRA, 2002)[1].

7.1.3 Foundries (castings)

The UK has a large foundry industry, employing directly around 25,000 employees in 450 companies, which are mainly located in the Midlands and South Yorkshire (Sheffield) area (ICME, 2012). Traditional demand drivers for iron castings are the oil &gas, engineering and railway sectors. Regarding steel castings, traditionally demand comes from mining, minerals and power generation projects. However, over the past years the foundry industry has been under pressure due to the recession (largely affecting sector it supplies such as the motor industry) and fierce overseas competition (CBI, 2010).

Foundries tend to be small scale and usually employ fewer than 50 people. Thus, at a stand-alone foundry, the range of contaminants present, and their concentrations is likely to be considerably smaller that at integrated steelworks. In this sense, only $PM_{2.5}$ emissions from the foundries industry can be considered relevant, and they account for 0.4% of total $PM_{2.5}$ UK’s emissions. These fugitive particulate emissions are primarily generated from the receiving, unloading, and conveying of the raw materials which include pig iron, iron and steel scrap, foundry returns, and metal turnings (DEFRA, 2002).

A7.2 Business as usual policies and abatement measures

The two main policy drivers for controlling air quality impacts of the sector are the Integrated Pollution Prevention and Control (IPPC) and the Large Combustion Plant (LCP) Directives, which are being replaced by Industrial Emissions Directive (IED) from 2016. The restrictions imposed by these policies have led to a number of abatement measures already being applied to the sector.

7.2.1 Sinter production

All UK sinter plants are fitted with conventional electro-static precipitators (ESPs). However, the composition of fine particulate matter (which includes alkali and lead chlorides) can form an insulating layer on the electrodes. Consequently, even when well designed and operated, conventional ESPs cannot normally achieve emitted dust concentrations of below 100-150 mg/m^3. PM_{10} emission factors from sinter plant have been reduced by 10% between 2000 and 2010 as a result of introducing moving electrode ESP.

SCR is technically feasible but it has not been applied at a sinter plant in Europe due to high investment and operational costs, the need for catalyst revitalisation, NH_3 consumption and slip and additional energy required for reheating (EC, 2012). Similarly, the regenerative activated carbon (RAC) process for desulphurisation and reduction of NOx has not been applied at a sinter plant in Europe due to high investment and operational costs in particular when high quality, expensive, activated carbon types may be used and a sulphuric acid plant is needed (EC, 2012).

An increasing number of plants in the EU have fabric filters in series after ESP for further cleaning of the gas and this technique has been included for consideration in the determination of BAT in the current draft of the BREF. Tata Steel ran a trial metal filter mesh on 5-8% of the gas stream at one site (Corus, 2008). The feasibility of full implementation is limited as the plant required is very large and there are difficulties with disposal of the by-product, however it is considered to be an alternative BBAU measure to fabric filters as each has comparable costs and performance. The main benefit of metallic filters is better resilience to high temperatures resulting in a longer filter life, but the technology is less well developed.

7.2.2 Coke production and coke ovens

SO_2 emissions are almost entirely attributable to the sulphur content of fuels used across the installation, rather than to process-specific factors. Tata Steel has developed an accurate sulphur balance for its Scunthorpe site, which is thought to be applicable to its other sites (Corus, 2008). The balance shows that coking coal accounts for approximately 80% of the total sulphur input to Scunthorpe Works. Approximately 25% of all sulphur in the combined inputs to the steelworks is emitted to air as SO_2. Approximately 50% of the SO_2 emission to air is attributable to combustion of coke oven gas at various combustion units across the entire steelworks. The sulphur content of COG is directly influenced by the sulphur content of the coking coal. The remaining SO_2 emissions result from combustion of coal in the sinter strand. There is little scope for reducing the sulphur content of coal further as low sulphur coal is already used (Corus, 2008). COG desulphurisation (various chemical processes exist to desulphurise COG) is not applied to any UK plant as the stringent permit limits in sulphur content of coal are adequate to minimise SO_2.

NOx emissions arising during coke production can be abated by reducing the flame temperature in the heating chamber and/or applying selective catalytic reaction (SCR). In the UK, Tata Steel's coke plant 2 in Scunthorpe is equipped with low-NOx firing systems. SCR can be applied to existing plants and has been implemented in Japan. However, the high cost has prohibited SCR ever being seriously considered for installation in European plants.

7.2.3 Combustion of fuels

SCR is considered to be a well established technique in some sectors that could be applied as a BBAU measure for combustion plant in the iron and steel sector.

Combustion of a mixed and variable fuel stream is fairly unique to the iron and steel sector. The variability does lead to lower combustion efficiencies than could be expected from a single fuel burner and therefore could be expected to result in higher PM emissions. Combustion plants contribute to a small percentage of the total inventory of PM releases from the integrated sites and so under normal circumstances investment into PM abatement would be more cost effective if made elsewhere. However, in order to comply with the proposed IED ELVs fabric filters or ESP could be required and so these are considered as BBAU measures.

7.2.4 Blast furnace and basic oxygen furnace

Blast furnaces are usually fitted with cyclones to achieve abatement of coarse mode particulates, and wet scrubbers or ESP for the removal of fine particulates. After abatement, blast furnace gas usually contains less than 10 mg/Nm^3 particulate matter (EC, 2012).

In basic oxygen furnace, as the iron is oxidised some of the particles are entrained into the flue gas. All basic oxygen furnaces are operated by Tata Steel and SSI (one in Teeside) and have secondary fume collection and abatement (Environment Agency, 2002). Gases escaping through the top of the vessel are cooled before being cleaned and discharged.

7.2.5 Electric arc furnaces

The most common dust abatement technique in EAF operations is the bag filter (also called bag house) which is particularly suited to the type of dust generated in the EAF. The off-gas flow from primary and secondary exhausting depends on the collection system. Most European EAF steelmaking plants use fabric filters for dust abatement, although it is not known whether UK EAFs have installed the fabric filters for dedusting.

7.2.6 Foundries (castings)

Dust emissions are produced during pouring, cooling and shake-out in foundries. The most commonly used system of reducing dust emissions from shake-out is a ventilator panel on the side of the shaker. The best way of achieving good emission levels with relatively small ventilation rates is when shake-out is performed in enclosed units. Appropriate techniques for dedusting are cyclones combined with wet scrubbers or dry filters. It is not known whether UK foundries have installed enclosure systems to reduce dust emissions.

A7.3 Beyond business as usual potential abatement measures

7.3.1 Sinter production

NOx

SCR can be applied to sinter plants. Although there are no sinter plants with SCR in Europe, an estimated cost of 30 million $€_{1997}$ is quoted for an SCR unit including a reheating system for a waste gas flow of 630,000 Nm^3 at Ijmuiden, the Netherlands plant of Tata Steel (EC, 2012). Operational costs of 1.5 – 2.0 $€_{1996}$ per tonne sinter for sinter plant with a waste gas flow of 1 million Nm^3, from another case study in EC (2012), are used for this analysis. An abatement efficiency of 90% and 100% BBAU uptake levels in 2025 and 2030 are assumed.

NOx, SO_2 and dust

RAC is based on regenerating of activated carbon which absorbs SO_2, where a high quality, expensive activated carbon type may be used and sulphuric acid (H_2SO_4) is yielded as a by-product. The bed is regenerated either with water or thermally. RAC may be an option for plants targeting SO_2, NOx, and dust together or in circumstances where ELVs are low. Regenerative activated carbon (RAC) can be applied as an end-of-pipe technique both at new and existing plants to remove several components from the off-gas (SO_2, HF, HCL, NOx, dust and PCDD/F) simultaneously. RAC can result in highly efficient desulphurisation (95 – 98%) and reduction of NOx (80 – 90%), but actual NOx abatement efficiency can be considerably lower (40 – 60%) depending on operating temperature, the addition of NH_3 and design (EC, 2012). The RAC process also reduces dust levels by approximately 20% (from 80 – 100 mg/Nm^3 to less than 20). An initial investment cost of 110 million $€_{2006}$ per plant for three sinter plants and operation and maintenance cost of 0.92 $€_{2006}$ per t sinter is assumed (EC, 2012).

The partial gas recycling technique is to recycle a part of mixed waste gas from the whole strand back to the entire surface of the strand. The waste gas is dedusted in a cyclone before being recycled through an additional fan to the hood above the strand. Partial recycling of waste gas was primarily developed to reduce waste gas flow and thus emissions of dust, but it also reduces NOx (40%) and SO_2 (20%). The investment required to implement this technique at the sinter plant at Tata Steel, Ijmuiden, the Netherlands with a total conventional waste gas flow of approximately 1.2 million Nm3/h from three sinter strands was 17 million $€_{2010}$. Operational costs decreased due to a reduced of input of coke breeze, resulting in operational savings of 2.5 million $€_{2010}$ per t coke breeze and sinter production of 4.2 Mt/year.

PM

Quoted fabric filter efficiencies are often based on instantaneous best performance. It is more realistic to use annual average performance as fabric filters cannot be used during start up and shut down and have to be taken off stream for blockages and cleaning etc, therefore the lower range in the BREF (95% from the Austrian case study) is considered to be suitable. Fabric filters and metallic mesh filters have been considered as alternative measures with comparable costs and performance, with 100% uptake of one or the other measure for estimated UK sinter production capacity. A capital cost of 4.17 $€_{2002}$/t sinter has been assumed using an Austrian plant example given in the BREF, as considered by Corus (2008) to be the most comparable for the UK. An operational cost of 0.54 $€_{1996}$/t sinter has been taken as the lower range in the BREF, on the basis that the upper end of the price range also includes costs of additive injection.

A bag filter can be combined with flow-injection using the MEROS® process (Maximised Emission Reduction of Sintering) or TFA process (Treatment des Fumes d'Agglomération) which uses hydrated lime to reduce SO_2 emissions. EC (2012) suggests an abatement efficiency of 98% for dust and 30 – 85% (average 57.5% used for analysis) for SO_2. The investment costs for new and existing plants is in the range of 16 to 35 $€_{2005}/Nm^3/h$ for upfront capital expenses and 0.3 to 0.6 $€_{2008}$/t sinter for operating costs (EC, 2012). Total waste gas flow was estimated by applying 0.25 Nm^3/h of waste gas per t sinter (EC, 2012) to NAEI projection of 7.671 million tonnes of sinter produced for 2025 and 2030.

Advanced electrostatic precipitator (ESP), which uses higher or variably pulsed voltages and rapid reaction voltage and current controls, can be applied for cleaning sinter plant waste gas at both new and existing plants (EC, 2012). An abatement efficiency of 98% is achievable, and the BBAU uptake level is assumed to be 100% for both 2025 and 2030. BREF suggests that investment costs depend on the waste gas flow and has an example of upfront expenses of 5 – 7.5 $€_{1996}/Nm^3/h$ and operational expenses of 0.05 – 0.08 $€_{1996}/Nm^3$ treated off gas.

7.3.2 Coke production and coke ovens

NOx

In the SCR process, NOx in the flue-gas is catalytically reduced by ammonia (NH_3) to nitrogen (N_2) and water (H_2O), using catalysts such as vanadium pentoxide, tungsten oxide on a titanium oxide, iron oxide and platinum. An abatement efficiency of 90% can be achieved (EC, 2012). BBAU uptake rate is assumed to be 100% for 2025 and 2030. Annualised cost is estimated based on the upfront investment cost of 15 $€_{1996}$ per plant for each of the three coke plants (i.e. 1 in Port Talbot; 1 in Teesside; 1 in Scunthorpe[2]) and the operational investment costs between 0.17 to 0.51 €$_{1996}$/tonne coke (EC, 2012).

SO_2

There are several types of coke desulphurisation system (see Table 5.17 of EC, 2012) and the most commonly used systems in Europe are Carl Still, Diamex, Ask or Cyclsulf, which use an ammonia liquor to scrub the H_2S from the coke oven gas (EC, 2012). Typical operating and capital costs for desulphurisation process of 95% abatement efficiency is suggested to be 9.2 €$_{2010}$/1000Nm^3 coke oven gas (EC, 2012). The annualised cost is then calculated using coke oven gas activity information (Mth coke oven gas consumed) from NAEI projections.

PM

A standard fugitive PM control measure is applied for fugitive PM emissions from coke production and stockpiles in integrated steelworks. See “Fugitive emissions of PM” chapter for a detailed description of the measure and cost analysis.

7.3.3 Combustion of fuels

NOx

Low-NOx burners and SCR are considered for BBAU scenario as they are applicable for reducing emissions from combustion of fuels in the sector. For Low-NOx burners, an average abatement efficiency of 12% (from a range between 9% and 15%) has been assumed in this analysis (Ontario Canada, 2010). BBAU uptake rate is assumed to be 90% for 2025 and 2030 to take into account that some boilers would be too small for the abatement techniques to be applied. The iron & steel sector analysis by Ontario Canada (2010) suggested the capital cost to range between 31 and 38 million \$$_{\text{can 2010}}$ and operating cost to range between 0.7 and 1.9 million \$$_{\text{can 2010}}$ per 1.1 to 1.9 kt of NOx reductions: average values of these ranges—23 million \$$_{\text{can 2010}}$/kt for investment cost and 0.9 million \$$_{\text{can 2010}}$/kt for operating cost—are used for this analysis.

SCR is considered to be a well established technique in some sectors that could be applied as a BBAU measure for combustion plant in the iron and steel sector. Integrated steel sites often have a large number combustion plants, and although the application of SCR is technically feasible, Corus (2008) considered installation on 20-50 MW units unlikely under BAU. Any new generating capacity, for example, at Scunthorpe or Port Talbot, would likely be required to meet more stringent limits than apply to existing plants, and therefore SCR is likely to be installed in these instances under the BBAU scenario. It is estimated that two thirds of the installed capacity is >50 MW and a potential uptake rate of 90% has been assumed on the basis that it is not applicable for the smallest boilers. The

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[2] There are two coke ovens in Scunthorpe: one is already fitted with low coking temperature (EC, 2012) and the other is assumed to be fitted with SCR by 2025 and 2030 under the BBAU scenario, along with coke ovens in Port Talbot and Teeside.

LCP BREF (EC, 2006) quotes a capital cost of 100 €$_{2006}$ per kW for small plant and the operating cost has been scaled at 6% of installation cost.

PM

Electrostatic precipitators (ESP) or fabric filters could potentially be applied to combustion plant to reduce PM emissions by 95%. A 90% uptake has been assumed for each, on the basis that 10% of installed capacity is likely to be small boilers for which such end of pipe technologies are not feasible. For ESP a capital cost of 35 €$_{2001}$ per kW has been taken from the LCP BREF, and an operational cost estimated at 4 €$_{2001}$ per kW.

Fabric filters require greater capital cost at 50 - 70 \$$_{2008}$ per kW (World Bank, date unspecified) (middle of range used for assessment) and an operational cost of 8 \$$_{2008}$ per kW scaled from the operating costs for fabric filters on sinter plants.

Although ESP is more cost effective there are practical reasons why fabric filters may be chosen in preference. Both measures have been assessed, but should be considered as alternative options. The actual uptake across the sector could be a mix of the two technologies.

7.3.4 Blast furnace and basic oxygen furnace

PM

A bag filter is considered to dedust the flue gas from the cast house of a blast furnace. EC (2012) lists example plants for different dedusting systems for the cast house in blast furnace in the EU, but this does not include any of the UK plants. Hence it is assumed that this abatement technique is not yet applied in the UK but has potential to be implemented up to 100% in 2025 and 2030. At Tata Steel, Ijmuiden, the Netherlands, investments for a bag filter system treating 690,000 Nm3/h were reported to be in the range of 1– 2.3 million €$_{2010}$ (EC, 2012). This only includes the bag filter equipment. Operational costs can be calculated as 0.5 – 2.8 €$_{2010}$/t hot metal, based on an annual production of 3 million tonnes hot metal per year in BF-7 and 8640 operational hours. An abatement efficiency of 95% is assumed.

Basic oxygen furnace (BOF) gas, which is generated during oxygen blowing, contains a large amount of dust. Primary dedusting can be performed by venturi-type scrubbers or dry and wet ESP at both new and existing plants. EC (2012) lists example plants for different dedusting systems in the EU, but this does not include any of the UK plants. Hence it is assumed that this abatement technique is not yet applied in the UK but has potential to be implemented up to 100% in 2025 and 2030. The investment costs for primary dedusting are between 24 - 40 million €$_{2010}$ for a 1Mt/yr steelmaking plant and the operational costs are 2 – 4€$_{2010}$/t liquid steel. An abatement efficiency of 80% is assumed (EC, 2012).

7.3.5 Electric arc furnaces

PM

A bag filter can be used to reduce dust from EAF for new and existing plants. The Iron and Steel BREF (EC, 2012) suggests an abatement efficiency of 95% but does not provide economic data on investment costs. As a result, we used the investment costs for using bag filters to reduce PCDD/F in at 0.5 – 1 million €$_{2010}$ for an EAF plant producing about 1 Mt steel/year, adjusted with the UK's total steel production from EAF from the NAEI projections. Operating costs are then calculated by applying the proportion of operating cost to investment cost from the sinter production bag filter measure. It is also assumed that the BBAU uptake levels could be 100% in 2025 and 2030.

Enclosure is another abatement technique for PM emissions from primary and secondary emissions. The combination of 4th hole (in case of three electrodes, e.g. Alternating Current) or 2nd hole (in the case of one electrode, e.g. Direct Current), the direct extraction with canopy hood systems (or furnace enclosures) or total building evacuation are the preferred systems. Furnace enclosures, also called doghouses, usually encapsulate the furnace and its swinging roof. Emissions from these enclosures can be abated up to 90% to 100% (EC, 2012). Investment costs are estimated using a case of two EAFs with capacity of 8.5 tonne/h: 275,000 €$_{2002}$ for construction of doghouse, 650,000 €$_{2002}$ for filtration/electrical units and approximately 1.9 million €$_{1996}$ of operating costs (i.e. depreciation, electric and repair cost). It is also assumed that the BBAU uptake levels could be 100% in 2025 and 2030.

7.3.6 Foundries (castings)

PM

Enclosure to capture dust emissions from foundries is considered. EC (2005) describes a Polish foundry for large-size cast steel castings where a removable doghouse type cover was constructed over the shake-out grate. The investment cost of 220,000 €$_{2005}$ is applied to 200 foundries in the UK to calculate total investment costs. As the Foundries BREF did not provide any information on the operational costs, it is assumed to be the same as the operating costs of enclosure for EAFs.

A7.4 Summary of measures and costs

Table 7.1 summarises the estimated cost of each abatement technology for the iron and steel sector. The costs in the summary table are based on the average cost of each abatement technology. Table 7.2 presents the reduction efficiency of the abatement measures and the associated reduction in emissions.

Table 7.1 Summary of beyond BAU abatement measures for the iron & steel sector for 2025 and 2030 [1]

Abatement measure	Future uptake of measure (%)		Operating life (years)	Capital Costs (£k, 2011 prices)		Annual operating costs (£k, 2011 prices)		Total annualised costs (£kpa, 2011 prices)	
	2025	2030		2025	2030	2025	2030	2025	2030
Sinter Production									
SCR	100%	100%	15	145,368	145,368	3,053	3,053	15,674	15,674
Regenerative activated carbon (RAC)	100%	100%	15	72,856	72,856	6,210	6,210	12,536	12,536
Partial Gas Recycling	100%	100%	15	46,041	46,041	4,122	4,122	8,120	8,120
Bag (fabric or metallic mesh) filter	100%	100%	15	26,847	26,847	3,897	3,897	6,228	6,228
Bag filter with flow-injection (e.g. MEROS) to reduce SO_2	100%	100%	15	40,970	40,970	3,011	3,011	6,568	6,568
Advanced ESP	100%	100%	15	11,276	11,276	1,045	1,045	2,024	2,024
Coke Production and Coke Ovens									
SCR	100%	100%	15	40,933	40,933	1,142	1,142	4,696	4,696
COG Desulphurisation	100%	100%	N/A	N/A	N/A	N/A	N/A	8,261	8,261
Combustion of fuels									
Low-NOx burners with external flue-gas recirculation	90%	90%	15	7,783	7,498	293	283	969	934
SCR	90%	90%	15	129,522	129,522	7,771	7,771	19,017	19,017
ESP	90%	90%	15	47,233	42,632	5,006	5,006	9,107	8,708
Bag filters	90%	90%	15	83,730	83,730	10,843	10,843	18,113	18,113

Abatement measure	Future uptake of measure (%)		Operating life (years)	Capital Costs (£k, 2011 prices)		Annual operating costs (£k, 2011 prices)		Total annualised costs (£kpa, 2011 prices)	
	2025	2030		2025	2030	2025	2030	2025	2030
Blast furnace and Basic oxygen furnace									
Dry or wet dedusting (ESP or scrubber) for BOF	100%	100%	15	229,807	229,807	21,544	21,544	41,497	41,497
Bag filter for BF	100%	100%	15	27,700	27,700	11,426	11,426	13,831	13,831
Electric arc furnace									
Bag filter	100%	100%	15	2,454	2,454	318	318	531	531
Enclosure	100%	100%	15	36,099	36,099	3,828	4,057	6,962	7,192
Foundries									
Enclosure to capture and treat exhaust gas from shake-out	100%	100%	15	36,863	36,863	3,828	3,675	7,029	6,875

Note 1: The costs presented here are the average costs for each abatement measure (in case a measure was given a range of costs). N/A is not available: for example if total annualised cost is presented in source data without capital and operating costs presented separately, or if the total annualised costs are calculated from data based on cost per tonne of pollutant abated. A discount rate of 3.5% is considered in the analysis.

Table 7.2 Summary of beyond BAU abatement measures efficiency for the Aluminium sector

Abatement measure	Emission reduction efficiency (%)						Reduction in 2025 emissions (kt)						Reduction in 2030 emissions (kt)					
	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3
Sinter Production																		
SCR	90%						9.47						9.47					
Regenerative activated carbon (RAC)	50%	97%	22%	22%			5.26	13.94	0.23	0.31			5.26	13.94	0.23	0.31		
Partial Gas Recycling	40%	20%	55%	55%			4.21	2.89	0.58	0.77			4.21	2.89	0.58	0.77		
Bag (fabric or metallic mesh) filter			95%	95%					0.99	1.33					0.99	1.33		
Bag filter with flow-injection (eg MEROS) to reduce SO2		58%	98%	98%				8.31	1.03	1.37				8.31	1.03	1.37		
Advanced ESP			98%	98%					1.03	1.37					1.03	1.37		
Coke Production and Coke Ovens																		
SCR	90%						4.80						4.80					
COG Desulphurisation by absorption system (Carl Still, Diamex, ASK or Cyclasulf)		95%						8.25						8.25				
Combustion of fuels																		
Low-NOx burners with external flue-gas recirculation	12%						1.67						1.60					
SCR	80%						3.51						3.38					
ESP			95%	95%					0.02	0.02					0.02	0.02		

Abatement measure	Emission reduction efficiency (%)						Reduction in 2025 emissions (kt)						Reduction in 2030 emissions (kt)					
	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3
Bag filters			95%	95%					0.02	0.02					0.02	0.02		
Blast furnace and Blast Oxygen Furnace																		
Dry or wet dedusting (ESP or scrubber)			80%	80%					0.40	0.80					0.40	0.80		
Bag filter			95%	95%					0.13	0.26					0.13	0.26		
Electric Arc Furnace																		
Bag filter (EAF)			95%	95%					0.12	0.20					0.12	0.22		
Enclosure (EAF)			95%	95%					0.12	0.20					0.12	0.22		
Foundries																		
Enclosure to capture and treat exhaust gas from shake-out (foundries)			95%	95%					0.18	0.18					0.17	0.17		

A7.5 References

1. CBI Market Survey (2010) "The castings and forgings market in the UK". http://www.gietech.be/LinkClick.aspx?fileticket=jsUshyjvNQg%3D&tabid=111&mid=539
2. Corus, 2008, personal communication 8th May 2008
3. DEFRA (2002), UK Particulate and Heavy Metal Emissions from Industrial Processes, Retrieved on 30/07/2012 from http://uk-air.defra.gov.uk/reports/empire/AEAT6270Issue2finaldraft_v2.pdf
4. EC (2005). Integrated Pollution Prevention and Control Reference Document on Best Available Techniques in the Smitheries and Foundries Industry. May 2005 http://eippcb.jrc.es/reference/BREF/sf_bref_0505.pdf
5. EC (2012) Reference Document on the Best Available Techniques for the Production of Iron and Steel http://eippcb.jrc.es/reference/BREF/IS_Adopted_03_2012.pdf
6. ICME, (2012) Institute of Cast Metals Engineers website. Retrieved on 30/07/2012 from http://www.icme.org.uk/about_castings.asp
7. Ontario Canada (2010). Appendix II: Ontario's Industry Emissions Reduction Plan: Abatement Cost Report for Nitrogen Oxides (NOx) and Sulphur Dioxides (SO_2).
8. UK Steel (2012), Retrieved on 30/07/2012 from http://www.eef.org.uk/uksteel/About-the-industry/How-steel-is-made/step-by-step/The-electric-arc-furnace.htm
9. UK Steel (2011), Annual review. http://www.eef.org.uk/uksteel/Publications/UK-Steel-Annual-Review-2011.htm
10. Tata Steel (2011), 104th Annual Report 2010-2011. http://www.tatasteel.com/investors/annual-report-2010-11/annual-report-2010-11.pdf
11. World Bank (date unspecified) Bagfilter/Baghouse, accessed May 2008, http://www.worldbank.org/html/fpd/em/power/EA/mitigatn/aqpcbag.stm

A8. Contents

A8. Aluminium

A8.1 Sector profile

Primary Aluminium

There is currently one operational primary aluminium smelter in the UK, and the remaining site is undergoing closure. The operating site is Lochaber, operated by Rio Tinto Alcan and located in the Scottish highlands. Lochaber has a production capacity of 45,000 tonnes per year. The other UK site, Lynemouth, is undergoing closure during 2012 so will not be relevant for 2025 and 2030 projections.

The NAEI projections indicate that primary aluminium production is a significant source of sulphur dioxide, with a contribution to UK SO_2 emissions of approximately 1%. The key source of SO_2 emissions during the primary aluminium production process is the consumption of anodes used during the electrolysis of bauxite. The anodes have a sulphur content of 1% to over 3.5%, and as the sulphur oxidises, they release sulphur dioxide emissions of 8 - 30 kg per tonne of aluminium (based on anode consumption of 0.4 tonne per tonne aluminium) (EC, 2009). Sulphur dioxide emissions primarily occur from flue-gases from the electrolysis cells, pot room ventilation and degassing processes.

Emissions also occur during the production of anodes, although these are a much lower contributor than the general production process. These emissions specifically relates to anode baking during production, during which SO_2 is released. Anode production had previously occurred at the Lynemouth smelter carbon plant, which were transported to the Lochaber site for use. It is understood that there is no anode production at Lochaber, but as there is activity data for anode production in 2025/30 it is assumed that production will continue somewhere in the UK.

Lochaber does not have significant SO_2 emissions associated with fossil fuel combustion as it is powered by a hydroelectric plant rather than fossil fuels.

The NAEI projections indicate that there are also emissions of NOx and PM10 and PM2.5 from primary aluminium production, but primary aluminium production is considered as an insignificant source compared to other UK sources.

Secondary Aluminium

The secondary aluminium sector produces aluminium from recycled sources, rather than electrolysis of bauxite. This includes both ‘new scrap’ such as unused off-cuts of metal, and ‘old scrap’ which has previously been used such as drinks cans. As of 2010, there were 39 secondary aluminium smelters in the UK. In 1996, it was reported that there were approximately 20 large smelters and a number of smaller ones, so it is assumed that there is still a split between large and small sites.

The NAEI projections indicate that secondary aluminium production is a source of UK PM10 and PM2.5 emissions, with each accounting for approximately 0.1% of UK emissions. No other types of emissions are forecast in the projections for secondary production.

The pre-treatment of metal and the melting stages of the secondary aluminium production process are the main contributor of PM emissions, followed by refining and degassing stages. PM emissions can also arise from the crushing of salt slag, which is a by-product of the process.

A8.2 Business as usual policies and abatement measures

Primary aluminium production is regulated under Integrated Pollution Prevention and Control (IPPC), but because Lochaber is powered by a hydroelectric plant it is not covered by the Large Combustion Plants Directive. Current BAT for primary aluminium relates to controlling to sulphur content of anodes and the use of scrubbing systems (EC, 2009), driven by the IPPC permit requirements. The Environment Agency guidance for permit compliance (2009) gives BAT sulphur control as controlling sulphur content of anodes only. The IPPC regulations will be replaced by the Industrial Emissions Directive, which is to be implemented by 2014 for sites currently under the IPPC regime. This will require existing BAT measures to be implemented as a requirement of the environmental permits.

For secondary aluminium smelters, fabric filters or wet scrubbers are currently BAT for the sector. Ceramic filters can offer greater PM abatement than fabric, and Alfed (n.d.) states that most secondary aluminium installations have fabric or ceramic filters in place. The large A1 sites are regulated under the Integrated Pollution Prevention and Control (IPPC) regime. BAT is to use fabric filters or wet scrubbers to reduce total particulates.

The A1 sites are required to reduce total particulates to 5 mg/m^3, and guidance for A2 and Part B sites regulated by Local Authorities are for 20 mg/m^3 particulate emissions. As the larger A1 installations are likely to already have fabric filters or wet scrubbers in place to comply with the more stringent permit conditions, there is little scope to further reduce PM emissions from those sites. The smaller A2 and Part B regulated sites, with a higher emission limit, have potential to reduce PM emissions by up to 75% (assuming that they meet the basic requirements of their permits, rather than going beyond this level). However, filtered particulates may be below this level depending on what filter is used on site, so the actual reduction may not be as great as this.

A8.3 Beyond business as usual potential abatement measures

8.3.1 Inert Anodes (primary aluminium)

SOx

Consumption of anodes is a key source of SO_2 emissions during the production process of primary aluminium. There is increasing interest in the use of inert anodes for the electrolysis reaction, which do not get consumed during the process and therefore do not release SO_2. This could eliminate SO_2 emissions from the primary aluminium production process. There are also reported to be reductions in CO_2 and PM emissions, although no reduction figures are included in the analysis at this time due to lack of information.

Research is currently underway on inert anodes, and the target timescale is for the anodes to be commercially operational by 2030. As such, this measure is not expected to be in place in 2025 but is assumed to be 100% in place in 2030, on the basis that inert anodes could be installed at the plant.

The capital expenses required to install this measure is based on the US Department of Energy (Kaempf, 2007) estimated retrofit costs for the replacement of anode cells of $\$_{2007}$ 1 – 2 million (mid-range used for assessment). The same source estimated a reduced operating cost of 3% compared to standard (non-inert) anodes. Some companies researching inert anodes, such as Rusal, estimate that the reduction in operating costs may be even greater. BREF gives average operating costs for primary aluminium production of $€_{1999}$ 1,225 per tonne aluminium, which was used with the 3% reduction in operating costs and the production capacity at Lochaber to give an estimated annual operating cost of $€_{1999}$ 53.5 million.

This measure affects SO_2 emissions from both the production process and anode production (although these emissions do not arise from Lochaber). Sulphur-containing anodes would not need to be produced in the UK if inert anodes were used at Lochaber.

8.3.2 Wet Scrubber (primary aluminium)

SOx

Wet scrubbers are used to remove SO_2 from the exhaust gases of the production process. This is understood not to be in place at Lochaber under BAU. AEAT (2002) stated that only one of the four UK smelters operating at the time of writing used a wet scrubber, and this smelter is understood to be Kinlochleven (as referred to in AEAT (1999)), which is now closed.

This measure only affects the production process emissions from Lochaber and not anode production taking place elsewhere. Sulphur-containing anodes would be produced off-site, and would not benefit from the emissions reduction associated with this measure. The abatement efficiency for wet scrubbers is presented in ENVIRON Corporation (2008) as 95% for SO_2. Uptake is 100% for 2025 and 2030 on the basis that this measure is currently available and could be installed at Lochaber.

Costs are based on a pre-feasibility report for a US primary aluminium smelter (Hatch, 2007), and the later ENVIRON Corporation report (2008) that scales these figures based on production capacity to obtain an estimate for refit costs for a second site. This later report provided a cost breakdown such that US tax could be excluded. Direct and indirect costs, such as contractor fees, performance testing and start-up, are included in the capital cost. The scaled estimated costs for Lochaber were $\$_{2007}$ 60.0 million for capital costs and $\$_{2007}$ 4.8 million for operating costs.

8.3.3 Filters for A2 and Part B sites (secondary aluminium)

PM10 and PM2.5

Fabric or ceramic filters are recommended in the BREF as BAT for secondary aluminium production, and it is common practice in the UK to have fabric filters or wet scrubbers in place.

As A2 and Part B sites are likely to have one set of filters in place already to meet the permit requirements, a second set of filters would be required to further reduce emissions. Additional filters can cause restrictions to exhaust fumes, and usually require exhaust conditions on permits, and would therefore not be applicable to all sites. Costs for second sets of filters could only be identified for sectors or measures where the differences are too great to draw any similarities. No suitable information on cost was therefore identified during the information review for a second set of filters for aluminium smelters or similar installations.

No emerging techniques or additional measures were identified in BREF or in the literature for secondary aluminium, so there are no measures included for secondary aluminium.

A8.4 Summary of measures and costs

Table A8.1 summarises the estimated cost of each abatement technology for the aluminium sector. The costs in the summary table are based on the average cost of each abatement technology. The range of costs were summarised in Section A8.3 for SO_2 abatement measures for primary aluminium production. Table A8.2 presents the reduction efficiency of the abatement measures and the associated reduction in emissions.

Table A8.1 Summary of beyond BAU abatement measures for the Aluminium sector (primary aluminium) for 2025 and 2030 [1]

Abatement measure	Future uptake of measure (%)		Operating life (years)	Capital Costs (£k, 2011 prices)		Annual operating costs (£k, 2011 prices)		Total annualised costs (£kpa, 2011 prices)	
	2025	2030		2025	2030	2025	2030	2025	2030
Inert anodes retrofit	0%	100%	15	0	854	0	50,123	0	50,197
Wet scrubber	100%	100%	15	34,119	34,119	2,741	2,741	5,703	5,703

Note 1: The costs presented here are the average costs for each abatement measure (in case a measure was given a range of costs). A discount rate of 3.5% is considered in the analysis.

Table A8.2 Summary of beyond BAU abatement measures efficiency for the Aluminium sector

Abatement measure	Emission reduction efficiency (%)						Reduction in 2025 emissions (kt)						Reduction in 2030 emissions (kt)					
	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3
Inert anodes retrofit		100%						0.00						1.33				
Wet scrubber		95%	50%	50%				1.29	0.01	0.01				1.24	0.01	0.01		

A8.5 References

1. AEAT (August 1999) “Speciated PAH inventory for the UK”
2. AEAT (February 2002) “UK Particulate and Heavy Metal Emissions from Industrial Processes”
3. Alfed (n.d.) “UK Aluminium Industry Fact Sheet 17: Primary Aluminium Production” http://www.alfed.org.uk/downloads/documents/1RAQY8V8Y1_17_aluminium_primary_production.pdf
4. American Society of Mechanical Engineers (July 1999) “Technical Working Group on Inert Anode Technologies”
5. EC (2009) “Integrated Pollution Prevention and Control Draft Reference Document on Best Available Techniques for the Non-Ferrous Metals Industries”
6. Defra (January 2006) “Sector Guidance Note IPPC SG4: Integrated Pollution Prevention and Control (IPPC) Secretary of State's Guidance for A2 Activities in the Non-ferrous Metals Sector”
7. Department of the Environment (1996) “Industry Profile: Metal manufacturing, refining and finishing works, non-ferrous metal works (excluding lead works)”
8. ENVIRON Corporation (February 2008) “BART Determination for Eastalco Aluminum Company, Frederick, Maryland”
9. Environment Agency (March 2009) “How to comply with your environmental permit: Additional guidance for: Non - Ferrous Metals and the Production of Carbon and Graphite (EPR 2.03)”
10. Hatch (November 2007) “Alcoa Primary Metals USA Pre-Feasibility Report: SO2 Scrubbing for the INTALCO Primary Aluminum Smelter”
11. Kaempf, D. (August 2007) “Industrial Technology Program”, US Department of Energy, presentation at Venture Capital Technology Showcase, 21/22 Aug 2007, p.70
12. Light Metal Age (2012) “Secondary Aluminum Smelters of the World” http://www.lightmetalage.com/producers.php#U
13. Rio Tinto Alcan (2009) “Lynemouth Smelter and Power Station Environmental Report 2008”
14. Rio Tinto (2012) “Group smelters and refineries” http://www.riotinto.com/annualreport2011/production_reserves_and_operations/group_smelters_and_refineries.html
15. Rusal (2012) “Inert anode technology” http://www.rusal.ru/en/development/innovations/inert_anode.aspx

A9. Contents

A9. Lead (secondary)

A9.1 Sector profile

Secondary lead production involves extracting the metal from used materials and recycling the scrap, opposed to production from ore. Much of this scrap is from old batteries, which contain lead alloy and lead oxide. This must be processed to extract the lead. Other sources can directly be melted down into new items, such as scrap metal, which can also be processed prior to melting if contaminated. The lead is then refined to remove impurities, and the lead is cast into ingots.

As of 2001, there were six secondary lead smelters in the UK. In the NAEI projections, secondary lead production accounts for approximately 1% of the UK total SO_2 emissions. Although there are also PM emissions associated with secondary lead production, these are viewed as insignificant compared to the rest of the UK emissions so are not considered here.

Batteries contain battery acid, which consists of sulphuric acid, and gives rise to sulphur dioxide ($S0_2$) emissions. The acid is drained from the battery, and the battery is usually crushed rather than processed to separate lead oxide, sulphate paste, and sulphuric acid, among others. Lead sulphate paste is usually desulphurised by reacting with sodium carbonate or sodium hydroxide.

A9.2 Business as usual policies and abatement measures

Emissions from lead smelters are controlled by the Integrated Pollution Prevention and Control (IPPC) regime. BAT listed in BREF (EC, 2009) for secondary lead production are to use a fabric or ceramic filter, or a wet electrostatic precipitator. Dust emissions should be reduced to 1 to 5 mg/m^3. IPPC will be replaced with the Industrial Emissions Directive, which must be implemented by 2014 for existing sites. This will require the existing BAT measures to be implemented in order to achieve compliance.

A9.3 Beyond business as usual potential abatement measures

9.3.1 Lead battery paste desulphurisation

SOx

An emerging technique included in BREF is the desulpheration of lead battery paste. This uses an amine-based solvent to separate acid or sulphate paste from the lead. Clean gypsum is produced, which is a by-product that can be sold. The solvent is reported to be regenerated, with no additional waste materials. A pilot scale plant has been developed in Poland, but no abatement efficiency or cost information was identified so this could not be included as a measure.

A9.4 Summary of measures and costs

No suitable measures and costs were identified for secondary lead production, as there was insufficient information available to develop the above measure for the MPMD.

A9.5 References

1. EC (July 2009) “Integrated Pollution Prevention and Control Draft Reference Document on Best Available Techniques for the Non-Ferrous Metals Industries”

2. Environment Agency (March 2009) “How to comply with your environmental permit: Additional guidance for: Non - Ferrous Metals and the Production of Carbon and Graphite (EPR 2.03)”

3. Thornton, I., Rautiu, R. and Brush, S. (2001) “Lead the Facts” http://www.ila-europe.org/UserFiles/File/factbook/leadTheFacts.pdf

A10. Contents

A10. Cement & Lime

A10.1 Sector profile

Cement

A database of cement plants operating in the UK, which includes information on the production technology and capacity of the plants, has been compiled using a variety of data sources[1,2,3,4,5]. There are currently 12 cement sites operating in the UK and many of these plants use different kiln systems. There are three main types of kiln systems which are shown below in Table A10.1.

Table A10.1 Types of cement kilns in the UK broken down by number of plants, kilns and kiln capacity

Kiln types	Wet process	Semi-dry process	Dry process
Number of plants	1	1	10
Number of kilns	1	1	12
Clinker kiln capacity (millions tonnes p.a.)	1.25	0.8	9.2

In 2030, the cement sector is projected to account for a significant proportion of total UK emissions of SO_2 (1.5%), NO_x (1.7%), PM10 (0.3%) and PM2.5 (0.3%)[6]. SO_2 and NO_x emissions to air are wholly from combustion processes (kilns)[7] whereas emissions of dust arise from crushing, grinding, conveyance and storage of raw materials and diffuse sources in addition to combustion processes. Although estimates of the proportion of dust emissions from diffuse sources are not available, they are considered to be small in comparison to emissions from

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[1] Natural Environment Research Council, (February 2008) 'British Geological Survey: Mineral Planning Factsheet – Cement'. Downloaded 31st May 2012 from: http://www.bgs.ac.uk/mineralsuk/

[2] Communication with the Mineral Products Association on the 22nd April 2009.

[3] Environment Agency (2009): 'Statutory Permit Review – Cement & Lime Sector: Phase 1 Sector performance review'.

[4] Discussion with the Environment Agency's 'Waste Incineration and Cement, Lime and Minerals Technical Adviser' on the 17th April 2012.

[5] Kilns which have ceased to operate (closed, mothballed) have been removed from the database for years following cessation of operations.

[6] NAEI UEP43 emission projections.

[7] European Commission (May 2010): Reference Document on Best Available Techniques in the Cement, Lime and Magnesium Oxide Manufacturing Industries. Downloaded 12th April 2012 from: http://eippcb.jrc.es/reference/BREF/clm_bref_0510.pdf

channelled dust emissions (kiln systems, clinker coolers and mills). For the purposes of this assessment it is assumed that 80% of dust emissions are from channelled emissions.

Lime

A database of lime plants operating in the UK, which includes information on the production technology and capacity of the plants, has been compiled using a variety of data sources[3,4]. There are currently 15 lime sites operating in the UK, 4 of which are lime kilns located at sugar production sites. Relatively little data on the capacity and types of kilns used in lime production in the UK is readily available. However, the Environment Agency permit review of lime kilns in 2009[3] provides some information on the number of lime and dolomitic lime plants in the UK, the number of kilns on-site and the types of kiln; this information is summarised in Table A10.2 (below).

Table A10.2 Types of lime kilns in the UK

Sector	Type of kiln	Number of plants	Number of kilns
Lime	ASK (1)	1	8
Lime	Rotary	1	1
Lime	PFRK (1)	2	3
Lime	Unknown (2)	5	13
Dolime	Rotary	2	10
Sugar	MFSK (Assumed) (3)	4	4

Note 1: Annular Shaft Kiln (ASK), Parallel Flow Regenerative Kiln (PFRK)

Note 2: These kilns are ‘captive’ lime kilns, where the lime is used in the production of soda ash; the kiln types are not known.

Note 3: Lime kilns at sugar installations are assumed to be Mixed Feed Shaft Kilns (MFSK) as this is the most common kiln-type for sugar lime kilns across the EU8

In 2030, the lime sector is projected to account for a significant proportion of total UK emissions of SO_2 (1.1%), NO_x (0.5%), PM10 (0.1%) and PM2.5 (0.1%)[6]. SO_2 and NO_x emissions to air are wholly from combustion processes (kilns)[7]. The major sources of dust at lime installations are kilns, lime hydrating operations, lime grinding and connected and subsidiary processes (crusher, storage, screening machines); emissions from these sources are typically ‘channelled’. In addition, there are some dust emissions from diffuse sources, but for the purposes of this assessment it is assumed that 100% of dust emissions are from channelled sources.

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[8] European Commission, (May 2010), ‘Reference Document on Best Available Techniques in the Cement, Lime and Magnesium Oxide Manufacturing Industries’. Available for download on the 12th April from: http://eippcb.jrc.es/reference/BREF/clm_bref_0510.pdf

A10.2 Business as usual (BAU) policies and abatement measures

10.2.1 Current BAU abatement measures

Cement

A number of data sources[3,9,10] have been examined to develop assumptions on current uptake (2010) of abatement measures in cement kilns in the UK to reduce emissions of SO_2, NO_x and PM_{10}. Table A10.3 (below) summarises the uptake of the main abatement measures at cement kilns in the UK.

Table A10.3 Estimated BAU uptake of abatement measures in the cement industry

Process	Pollutant	Measure	2010 uptake (% kilns)
Kiln	SO_2	Wet scrubber	14%
Kiln	NO_x	Low-NOx burners	100%
Kiln	NO_x	Process optimisation	100%
Kiln	NO_x	Selective Non-Catalytic Reaction (SNCR)	79%
Kiln & other channelled emissions	Dust	Bag filters	50%
Kiln & other channelled emissions	Dust	Electrostatic Precipitator (ESP)	50%

Lime

A number of data sources[3,10,11] have been examined to develop assumptions on current uptake (2010) of abatement measures in UK lime kilns to reduce emissions of SO_2, NO_x and PM_{10}. Table A10.4 (below) summarises the uptake of the main abatement measures at lime kilns in the UK (not including kilns at sugar installations[12]).

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[9] The Environment Agency, (November 2010), 'How to comply with your environmental permit. Additional guidance for: The cement industry (EPR 3.01a). Available for download on the 11th April 2012 from: http://www.environment-agency.gov.uk/static/documents/Business/How_to_Comply_-_Cement_EPR3_01a.pdf

[10] Discussion with the Environment Agency's 'Waste Incineration and Cement, Lime and Minerals Technical Adviser' on the 17th April 2012.

[11] The Environment Agency, (November 2010), 'How to comply with your environmental permit. Additional guidance for: The lime industry (EPR 3.01b). Available for download on the 11th April 2012 from: http://www.environment-agency.gov.uk/static/documents/Business/How_to_Comply_-_Lime_EPR3_01b.pdf

[12] Abatement measure uptake for lime kilns operating at sugar sites have not been examined, as: no data is available on the current or future abatement measures (sugar sites are excluded from EA permit review).

Table A10.4 BAU Abatement measures in the lime industry (not including kilns at sugar sites)

Process	Pollutant	Measure	BAU (2010) Uptake (% kilns)
Kiln	SO_2	Wet scrubber	3%
Kiln	SO_2	Low-S fuel selection	100%
Kiln	NO_x	Process optimisation	100%
Kiln	NO_x	Low-NOx burners	100%
Kiln	NO_x	Oxygen injection	9%
Kiln & other channelled emissions	Dust	Bag filters	74%
Kiln & other channelled emissions	Dust	Electro-static Precipitator (ESP)	6%

10.2.2 Legislation

Currently, the main policy drivers for controlling air quality impacts of the sector are the Integrated Pollution Prevention and Control (IPPC) Directive[13], the Waste Incineration Directive[14] and their successor, the Industrial Emissions (Integrated Pollution Prevention & Control) Directive (IED)[15]. In England & Wales, guidance on the current abatement requirements and associated emission levels for cement and lime plants required in the UK to comply with the WI and IPPC Directives is given in two guidance documents[9,11]; these documents include consideration of the Best Available Techniques stipulated in the latest version of the Cement, Lime and Magnesium Oxide Manufacturing Industries BREF[7]. The IED[15] will supersede the WI and IPPC Directives and once transposed into UK law (required by January 2013) will apply to new installations from 6th January 2013 and existing plants from 6th January 2014[16].

For cement kilns co-incinerating waste, Annex VI (2) of the IED includes concentration limit values for emissions to air from the WID. Not all of these requirements have not been included in the UK guidance notes[9,11] and UK guidance may therefore be updated to incorporate them; although there is still some uncertainty over how the IED

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[13] European Commission, (24 September 1996), 'Council Directive 96/61/EC of 24 September 1996 concerning integrated pollution prevention and control'. Available for download on the 12th April 2012 from: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:1996:257:0026:0040:EN:PDF

[14] European Commission, (4 December 2000), 'Directive 2000/76/EC of the European Parliament and of the council of 4 December 2000 on the incineration of waste'. Available for download on the 12th April 2012 from: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2000:332:0091:0111:EN:PDF

[15] European Commission, (24 November 2010), 'Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control) (Recast)'. Available for download on the 12th April 2012 from: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:334:0017:0119:EN:PDF

[16] Department for Environment Food and Rural Affairs (Defra) website - Industrial Emissions Directive: http://www.defra.gov.uk/environment/quality/industrial/eu-international/industrial-emissions-directive/

will be implemented in the UK. Table A10.5 (below) summarises the current UK requirements for emissions to air for cement and lime plants and any additional requirements which will be required in the future under the IED for existing plants.

The IED does not explicitly introduce any new requirements for cement and lime kilns which do not incinerate waste. However, Article 15(3) of the IED strengthens the status of BREF[7] documents and requires competent authorities to *'take BAT conclusions into account in permitting'* and '*to set ELVs, ensuring that, under normal operating conditions, emissions do not exceed the emission levels associated with best available techniques (BAT-AEL*[17]*), as laid down in the BAT conclusions'*[18]. It should be noted that, the IED, like IPPC offers some flexibility in how BAT standards should be applied, but the scope for deviation from BAT conclusions will be more difficult than under IPPC. BAT conclusions for the cement and lime industries are currently being drafted; the BREF document is likely to be published later in 2012[19]. Once the BAT conclusions are published, the UK competent authorities are required to review relevant plant permits and conditions within four years making changes where necessary and the plant must comply with any changes within the same time period. Although the BAT-AEL conclusions have not yet been published, a summary of the probable BAT-AELs that will be adopted and an initial assessment of how these are likely to affect UK Guidance and permit conditions for existing plants are included in the table below[19].

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[17] Best Available Technique – Associated Emission Level (BAT-AEL)

[18] European Environmental Bureau, (14th July 2011), 'New Features under the Industrial Emissions Directive'. Available for download on the 17th April 2012 from: http://www.eeb.org/?LinkServID=290B7936-ADF0-4AD8-D16350AB49EE7DFC&showMeta=0

[19] Discussion with the Environment Agency's 'Waste Incineration and Cement, Lime and Minerals Technical Adviser' on the 17th April 2012.

Table A10.5 Comparison of current UK BAT guidance and potential additional requirements under IED for cement and lime plants

Plant Type	UK Guidance for compliance with IPPC and WID and BAT recommendations from the BREF (May 2010)	Additional Requirements under the IED.
Cement plants (no co-incineration of waste)	NO_x kiln emissions: BAT requirements – A combination of: 1) Primary measures to reduce NO_x emissions (flame cooling, low NO_x burners, mid kiln firing, addition of mineralisers, use of waste-derived fuels); 2) Staged combustion, in combination with a pre-calciner and optimised fuel mix; 3) Selective non-catalytic reduction (SNCR) techniques. In order to meet concentration limits: Pre-heater kilns - 200-450 mg*/Nm^3 (1) (2) Lepol and long rotary kilns - 400-800 mg*/Nm^3 (2) *NO_x expressed as NO_2 (1) The upper limit is 500 mg*/Nm^3 when the level is above 1,000 mg*/Nm^3 after primary measures have been applied (2) Depending on levels of ammonia slip and NO_x levels.	Although the BAT conclusions have not yet been published it is currently thought that[19]: - The upper limit in the NO_x BAT-AEL range is likely to be 500 mg/Nm^3; - The UK is likely to apply this upper limit and will re-issue permits including this as an improvement condition following the confirmation of the BAT-AEL range (expected late 2012); - Permits will have to be reviewed and plants will have to comply with improvement conditions, within 4 years of the BAT conclusions being adopted in the UK; - Most plants will be able to meet this limit by implementing the improvement conditions identified in the 2009 permit review and by increasing the efficiency of SNCR equipment; improvements are expected for most plants by 2016.
	SO_2 kiln emissions: BAT requirements – A combination of: 1) Limit the sulphur content of raw materials entering the kilns where practicable; 2) Use absorbent addition; 3) Use a wet scrubber. In order to meet concentration limits: All kilns - <50-400 mg*/Nm^3 *SO_x expressed as SO_2	Although the BAT conclusions have not yet been published it is currently thought that[19]: - The upper limit in the SO_x BAT-AEL range is likely to be 400 mg/Nm^3; - The UK is likely to apply this upper limit and will re-issue permits including this as an improvement condition following the confirmation of the BAT-AEL range (expected late 2012); - Permits will have to be reviewed and plants will have to comply with improvement conditions in the reissued permits, within 4 years of the BAT conclusions being adopted in the UK; - Most plants will be able to meet this limit by implementing the improvement conditions identified in the 2009 permit review; improvements are expected for most plants by 2016.

Plant Type	UK Guidance for compliance with IPPC and WID and BAT recommendations from the BREF (May 2010)	Additional Requirements under the IED.
	Dust emissions (kiln and other point sources (e.g. clinker coolers, milling)): BAT requirements - Minimise dust emissions from all point source releases of dust (kiln exhaust, clinker coolers, milling operations) by using bag filters or ESPs. To achieve emissions of particulate matter (PM) from kilns of: All kilns - <10-20 mg PM / Nm^3	Although the BAT conclusions have not yet been published it is currently thought that[19] - The upper limit in the PM BAT-AEL range for kiln exhasut is likely to be 20 mg*/Nm^3; - The UK is likely to apply this upper limit and will re-issue permits including this as an improvement condition following the confirmation of the BAT-AEL range (expected late 2012); - Permits will have to be reviewed and plants will have to comply with improvement conditions in the reissued permits, within 4 years of the BAT conclusions being adopted in the UK; - Most plants will be able to meet this limit by implementing the improvement conditions identified in the 2009 permit review; improvements are expected for most plants in 2016.
Cement plants (co-incineration of waste)	NO_x kiln emissions: Abatement measures as described above. WID emission limit – 800 mg*/Nm^3 *NO_x expressed as NO_2	Emission concentration limit in Annex VI of IED: 500 mg*/Nm^3 (1) (1) Until the 1 January 2016 competent authorities may authorise exemptions for Lepol Kilns and Long rotary kilns provided that the maximum concentration limit in the permit is 800 mg*/Nm^3 *NO_x expressed as NO_2 The eventual adoption of the BAT conclusions may require the UK guidance and permit conditions to be updated to a lower concentration limit.
	SO_2 kiln emissions: Abatement measures as described above. WID emission limit – 500 mg*/Nm^3 (1) *SO_x expressed as SO_2 (1) Exemption may be granted if it can be demonstrated that SO_2 emissions are not the result of the incineration of waste.	Emission concentration limit in Annex VI of IED: 50 mg*/Nm^3 (1) *SO_x expressed as SO_2 (1) Exemption may be granted if it can be demonstrated that SO_2 emissions are not the result of the incineration of waste. The transposition of the IED in the UK following the publication of the BAT Conclusions may require the UK guidance and permit conditions to be updated to a lower concentration limit.

Plant Type	UK Guidance for compliance with IPPC and WID and BAT recommendations from the BREF (May 2010)	Additional Requirements under the IED.
	Dust emissions (kiln and other point sources (e.g. clinker coolers, milling)): Abatement measures as described above. WID emission limit – 30 mg PM / Nm^3	Emission concentration limit in Annex VI of IED: 30 mg/Nm^3 The transposition of the IED in the UK following the publication of the BAT conclusions may require the UK guidance and permit conditions to be updated to a lower concentration limit (see discussion below table)
Lime plants (no co-incineration of waste)	NO_x kiln emissions: BAT requirements – A combination of: 1) Select fuels with low nitrogen content; 2) Use optimised flame shaping and temperature profiling 3) Use Low NO_x burners; 4) Use selective non-catalytic reductions (SNCR) techniques. In order to meet concentration limits: PRFK, ASK, MFSK, OSK kilns - 100-350 mg^*/Nm^3 (1) LRK. PRK kilns - <200-500 mg^*/Nm^3 (2) *NO_x expressed as NO_2 (1) An upper limit of 500 mg^*/Nm^3 for hard-burned lime when secondary measures are not available. (2) An upper limit of 800 mg^*/Nm^3 for hard-burned lime	Although the BAT conclusions have not yet been published it is currently thought that[19]: - The upper limits in the NO_x BAT-AEL range are likely to be the same as in current UK guidance (see left) - The UK is likely to adopt these upper limits and, if necessary, will re-issue permits including this as an improvement condition following the confirmation of the BAT-AEL range (expected late 2012); - Permits will have to be reviewed and plants will have to comply with improvement conditions in the reissued permits, within 4 years of the BAT conclusions being adopted in the UK; - Most plants will be able to meet this limit by implementing the improvement conditions set in the 2009 permit review; improvements are expected for most plants in 2016; - The exception is dolomitic plants which may not be able to meet the limits due to higher combustion temperatures; derogations may be applied in the UK.

Plant Type	UK Guidance for compliance with IPPC and WID and BAT recommendations from the BREF (May 2010)	Additional Requirements under the IED.
	SO_2 kiln emissions: BAT requirements – a combination of: 1) Use process optimisation to ensure efficient absorption of SO_2; 2) Select fuels with a low sulphur content if using long rotary kilns; 3) Use additions of an absorbent into the exhaust gas stream if using long rotary kilns; 4) Use a wet scrubber. In order to meet concentration limits: PFRK, ASK, MFSK, OSK, PRK kilns - <50-200 mg*/Nm^3 LRK kilns - <50-400 mg*/Nm^3 *SO_x expressed as SO_2	Although the BAT conclusions have not yet been published it is currently thought that[19]: - The upper limits in the SO_x BAT-AEL range are likely to be the same as in current UK guidance (see left); - The UK is likely to adopt these upper limits and will, if necessary, re-issue permits including this as an improvement condition following the confirmation of the BAT-AEL range (expected late 2012); - Permits will have to be reviewed and plants will have to comply with improvement conditions in the reissued permits, within 4 years of the BAT conclusions being adopted in the UK; - Most plants will be able to meet this limit by implementing the improvement conditions set in the 2009 permit review; improvements are expected for most plants in 2016.
	Dust emissions (kiln and other point sources (e.g. milling)): BAT requirements – The following measures should be applied: 1) Minimise dust releases from all point sources using fabric filters or electrostatic precipitators (ESPs); 2) Minimise dust releases from point source releases from lime hydrating plants use a wet scrubber or other suitable abatement. To achieve emissions of particulate matter (PM) from kilns of: Kilns with fabric filters - <10 mg PM / Nm^3 Kilns with ESPs - <20 mg PM / Nm^3 (1) (1) In exceptional circumstances, where the resistivity of dust high, the upper limit is 30 mg PM / Nm^3,	Although the BAT conclusions have not yet been published it is currently thought that[19]: - The upper limits in the BAT-AEL range is likely to be <20 mg PM / Nm^3; - The UK is likely to adopt this upper limit and will re-issue permits including this as an improvement condition following the confirmation of the BAT-AEL range (expected late 2012); - Permits will have to be reviewed and plants will have to comply with improvement conditions in the reissued permits, within 4 years of the BAT conclusions being adopted in the UK; - Most plants will be able to meet this limit by implementing the improvement conditions set in the 2009 permit review; improvements are expected for most plants in 2016.

Plant Type	UK Guidance for compliance with IPPC and WID and BAT recommendations from the BREF (May 2010)	Additional Requirements under the IED.
Lime plants (co-incineration of waste)	NO_x kiln emissions: Abatement measures as described above. WID emission limit is based on a weighted average (on the basis of fuel calorie input) of emission limits contained in Annex V of WID..	Emissions concentration limits described in the IED Annex VI use the same formula and concentration limits for waste plants contained in WID. The transposition of IED in the UK will not require additional NO_x abatement measures for lime plants co-incinerating waste.
	SO_2 kiln emissions: Abatement measures as described above WID emission limit is based on a weighted average (on the basis of fuel calorie input) of emission limits contained in Annex V of WID.	Emissions concentration limits described in the IED Annex VI use the same formula and concentration limits for waste plants contained in WID. The transposition of IED in the UK will not require additional SO_2 abatement measures for lime plants co-incinerating waste.
	Dust emissions (kiln and other point sources (e.g. milling)): Abatement measures as described above WID emission limit is based on a weighted average (on the basis of fuel calorie input) of emission limits contained in Annex V of WID.	Emissions concentration limits described in the IED Annex VI use the same formula as contained in WID and the same emission concentrations limit for waste plants . The transposition of IED in the UK will not require additional dust abatement measures for lime plants co-incinerating waste.

Note: Long Rotary Kiln (LRK), Rotary Kiln with Preheater (PRK), Parallel Flow Regenerative Kiln (PFRK), Annular Shaft Kiln (ASK), Mixed Feed Shaft Kiln (MFSK), Other Shaft Kilns (PSK).
Note 2: All concentration limit values presented are daily average values.

10.2.3 Expected future BAU abatement uptake

Before the adoption and publication of the BAT conclusions for the cement and lime industries it is not possible to conclusively state what concentration limits will be used in UK Guidance or what the improvement conditions required of UK plants will be, although it is expected that they will be based on the 2010 BREF; therefore this issue should be revisited once new UK permits have been issued.

Currently, the Environment Agency[19] estimates that compliance with the IED in the UK will result in the review and reissue of current permits to cement and lime plants in the UK, with the following amendments to permits:

- The wording of the permit improvement conditions will be amended to make the improvement conditions more binding;
- The permits for cement plants may additionally be altered to include a lower daily concentration limit for NO_x (500mg/Nm^3); all plants should be able to meet this NO_x limit by implementing permit improvement conditions and increasing the abatement efficiency of SNCR; and
- Permits are expected to be reissued in 2013 and sites are expected to have a four year compliance window; implementation of these measures is expected in 2016.

Table A10.6 (below) summarises the expected uptake of the main abatement measures in the cement industry in 2016, incorporating assumptions on the abatement measures required to meet permit improvement conditions[20] and any other planned abatement measures known of; the figures in brackets show the current (2010) uptake of each measure.

Table A10.6 Projected uptake of abatement measures in the cement sector by 2016

Process	Pollutant	Measure	2016 projected uptake (% kilns)
Kiln	SO_2	Wet scrubber	36% (14%*)
Kiln	NO_x	Process optimisation	100% (100%*)
Kiln	NO_x	Low-NOx burners	100% (100%*)
Kiln	NO_x	SNCR	93% (79%*)
Kiln	NO_x	SNCR – Increased use to meet 500mg/Nm^3 limit (1)	79% (N/A*)
Kiln & other channelled emissions	Dust	Bag filters	50% (50%*)
Kiln & other channelled emissions	Dust	Electrostatic Precipitator (ESP)	50% (50%*)

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[20] Environment Agency, (14th May 2010), ‘Statutory Permit Review – Cement and Lime Sector: Phase 2 Permit Review Plan’.

Process	Pollutant	Measure	2016 projected uptake (% kilns)
Kiln & other channelled emissions	Dust	Upgrade of bag filter / ESP units (2)	93% (N/A*)

* Figures shown in brackets indicate the uptake of abatement measures in 2010.

Note 1: Plants will be required to meet a reduced NOx ELV of 500mg/Nm^3 (dry kilns), which is assumed to require the installation of SNCR (if none present) and increasing the efficiency of existing SNCR.

Note 2: Plants will be required to meet a reduced ELV for dust of <10-20mg/Nm^3, where the previous limit was 30mg/Nm^3. Where bag filters are already installed, the new limits could be met by reducing the replacement interval for filters. Where ESP is installed, the new limit could be met by upgrading them, or replacing ESPs with bag filters.

Table A10.7 (below) summarises the expected uptake of the main abatement measures in the lime industry (not including lime kilns at sugar plants) by 2016, incorporating assumptions on the abatement measures required to meet permit improvement conditions[20] and any other planned abatement measures known of; the figures in brackets show the current (2010) uptake of each measure.

Table A10.7 Projected uptake of abatement measures in lime sector (not including kilns at sugar sites) by 2016

Process	Pollutant	Measure	2016 projected uptake (% kilns)
Kiln	SO_2	Wet scrubber	9% (3%*)
Kiln	SO_2	Low-S fuel selection	100% (100%*)
Kiln	NO_x	Process optimisation	100% (100%*)
Kiln	NO_x	Low-NOx burners	100% (100%*)
Kiln	NO_x	Oxygen injection	9% (9%*)
Kiln	NO_x	Selective Non-catalytic Reduction (SNCR) (1)	11% (0%*)
Kiln & other channelled emissions	Dust	Bag filters (2)	91% (74%*)
Kiln & other channelled emissions	Dust	Electro-static Precipitator (ESP)	6% (6%*)
Kiln & other channelled emissions	Dust	Upgrade of bag filter / ESP units (3)	17%

* Figures shown in brackets indicate the uptake of abatement measures in 2010.

Note 1: Installation of SNCR has been assumed for sites which have a significant reduction in NO_x emissions (e.g. 2,200 -> 800 mg/Nm^3) listed in the permit improvement conditions.

Note 2: The upper limit of the range assumes that kilns at soda ash production installations have bag filters installed as BAU in 2010; the dust abatement measures applied at soda ash production facilities were not included within the sector reviews.

Note 3: Upgrading of bag filers / ESP has been assumed for plants which do not currently meet the proposed ELVs[20] for dust emissions from kilns. As soda ash production installations were included within the sector review[Error! Bookmark not defined.] it is not possible to state whether these installations will require improved dust abatement.

A10.3 Beyond business as usual potential abatement measures

10.3.1 Cement Sector

NO_x emissions

Two NO_x abatement techniques considered beyond BAU (at least for some sites) for the cement sector are:

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

However, as the two measures are mutually exclusive and the majority of cement installations have installed low efficiency SNCR as BAU, SCR was not considered further.

SNCR can achieve NO_x level reductions in the region of 200mg/m^3 to 800mgN/m^3. However data provided by the EA suggests that SNCR installed before 2012 has been designed to reduce NO_x emissions from an initial level (post primary measures) level of ~1,200mg/Nm^3 to meet a limit of 800mg/Nm^3; therefore the measure SNCR (low), with an efficiency of 33%, has been assumed to be in place in 2010 at the majority of cement installations. The capital costs for SNCR (low) have been calculated as the average of the low estimate of the range included in the 2010 BREF and the high estimate of the range provided by BCA (2008). The lower estimate of operating costs provided by BCA in 2008 have been used, as this relates to the use of SNCR with a low molar ratio.

The EA's 2010 permit review included improvement conditions for several cement plants to further reduce NO_x emissions from an initial level of 800mg/Nm^3 to meet a limit of 500mg/Nm^3. It was assumed that this additional reduction would only be possible through increasing the molar ratio (NH_3 / NO_x) in the SNCR unit; therefore the measure SNCR (high), with an efficiency of 38%, has been assumed to be installed in 2016 for those cement plants which have an improvement condition for NO_x emissions included in the permits issued in 2010. It has been assumed that installations which have already installed SNCR (low) will not face any additional capital costs when operating SNCR with a higher molar ratio (SNCR (high)) as the majority of the equipment is already installed; in practice SNCR (high) may require additional spray nozzles and ammonia storage, but no cost estimates were available. The higher estimate of operating costs provided by BCA in 2008 has been used, as this relates to the use of SNCR with a high molar ratio.

The maximum potential further uptake of these measures has been estimated on the basis of NO_x emissions at plants which have already installed SNCR (low), but have not upgraded to SNCR (high) under BAU; this information is based on site-specific assumptions from the NAEI which have recently been developed for the sector as part of an on-going package of work to integrate technology uptake assumptions into the overall NAEI projections database.

SO_2 emissions

Wet scrubbers - SO_2 emissions

A wet scrubber can be fitted to all kiln types. The SO_2 is absorbed by a liquid/slurry sprayed in a spray tower or the gases are bubbled through the liquid/slurry. The absorbent can be calcium carbonate, hydroxide or oxide. The reduction of SO_2 can be more than 90% with the added advantage that wet scrubbers can also reduce emissions of HCI, residual dust (i.e. PM), metal and NH_3.

According to the EA sector review[20], wet scrubbers are in operation at two plants. In addition, it has been assumed that wet scrubbers will be installed at a further two plants to meet the SO_2 limits proposed in the EA sector review[20]. The maximum potential further uptake of this measure has been estimated on the basis of SO_2 emissions at plants which are assumed not to have installed wet scrubbers under BAU in 2025/2030; this information is based on site-specific assumptions from the NAEI.

Capital and operating cost estimates are based on information provided by BCA in 2008 and updated to current prices.

Dry scrubber - SO_2 emissions

A dry scrubber can only be fitted to dry kiln types, with an efficiency reduction estimated at up to 90%. When SO_2 emissions are more than 1,500mg/Nm^3 a scrubber is likely to be required. It is also known to reduce HCI and HF emissions. The intensive contact between gas and absorbent, the long residence time and the low temperature (close to the dew point) allow efficient absorption of SO_2 (EC, 2007).

There are currently no plants with dry scrubbers in Europe (and possibly worldwide). According to the BREF the dry scrubber is currently more expensive than the wet scrubber. Given a wet scrubber can potentially abate more SO_2 it is unlikely that any plant would install a dry scrubber. This abatement technique is considered beyond BAU and unlikely to be taken up in the future unless there are significant developments which reduce the cost of dry scrubbers. Therefore this measure is not considered any further.

Absorbent addition - SO_2 emissions

The additions of absorbents such as slaked lime ($Ca(OH)_2$), quicklime (CaO), sodium bicarbonate or activated flash ash with high CaO content to the exhaust gas of the kiln can absorb some of the SO_2. Absorbent additions can be used on all kiln types for initial levels up to 1,200 mg/m^3. At initial levels above 1,200 mg/m^3, adding slack lime to the kiln feed is not cost effective. SO_2 reductions of up to 60-80% can be achieved by absorbent injections in suspension preheater kiln systems; an SO_2 reduction efficiency of 70% is assumed.

According to the BREF (EC 2010) absorbent addition is currently in use at several plants to ensure that the current limits are not exceeded in peak situations. This means that in general it is not in continuous operation, but only when required under specific circumstances. The Mineral Products Association (MPA, 2009) argue that absorbent addition is only applicable on preheater/precalciner kilns and would not be applied to those kilns already fitted with wet scrubbers. The maximum potential further uptake of this measure has been estimated on the basis of SO_2

emissions at preheater and precalciner plants which are assumed not to have installed wet scrubbers under BAU in 2025/2030; this information is based on site-specific assumptions from the NAEI.

Capital and operating cost estimates are based on information provided by BCA in 2008 and updated to current prices.

Activated carbon - SO_2 emissions

Activated carbon can only be fitted to dry kiln types, with an SO_2 efficiency reduction estimated at up to 95%. SO_2, organic compounds, metals, NH_3, NH_4 compounds, HC1, HF and residual dust (after an electrostatic precipitators (EP) or fabric filter) emissions may be removed from the exhaust gases by adsorption on activated carbon. If NH_3 is present, or added, the filter will also remove NO_x as well (EC, 2007). The only activated carbon filter installed at a cement works in Europe is that at Siggenthal, Switzerland.

Without a significant drop in costs, most sites will opt to install a wet scrubber instead if significant SO_2 reductions are required as activated carbon is the most expensive abatement measure to reduce SO_2 emissions. Therefore this measure is not considered any further.

PM emissions

According to the EA sector review, some plants will be required to meet a reduced ELV for dust of <10-20mg/Nm^3, where the previous limit was 30mg/Nm^3. Where bag filters are already installed, the new limits could be met by reducing the replacement interval for filters. Where ESP is installed, the new limit could be met by upgrading them, or replacing ESPs with bag filters. It has been assumed that all plants with an improvement condition identified from the EA sector review will improve the applicable abatement measure to meet the new limit of <10-20mg/Nm^3 by 2016.

Therefore, no BBAU measures have been developed for PM emissions.

10.3.2 Lime Sector

NO_x emissions

SNCR (low) and SNCR (high) have been included as BBAU measures for the lime sector, but at present can only be considered applicable to preheater rotary kilns. The maximum potential further uptake of these measures has been estimated on the basis of NO_x emissions at preheater rotary kilns which have already installed SNCR (low), but have not upgraded to SNCR (high) under BAU; this information is based on site-specific assumptions from the NAEI.

Cost estimates are taken from the BREF (2010) and adjusted to current prices:

- The average capital cost is used for SNCR (low);

- SNCR (high) is assumed to have no capital cost (see cement); and
- The low operating cost estimate is used for SNCR (low) and the high estimate for SNCR (high).

SO_2 emissions

As for the cement sector, wet FGD and absorbent addition are included as BBAU measures for the lime sector.

Wet scrubbers - SO_2 emissions

As no cost estimates specific to the lime sector were available in the BREF (2010), the cement cost estimates have been adjusted on the basis of dry exhaust gas volumes per unit of capacity and updated to current prices.

According to the EA sector review[20], wet scrubbers are in operation at one site. In addition, it has been assumed that wet scrubbers will be installed at a further plant to meet the SO_2 limits proposed in the EA sector review[20]. The maximum potential further uptake of this measure has been estimated on the basis of SO_2 emissions at plants which are assumed not to have installed wet scrubbers under BAU in 2025/2030; this information is based on site-specific assumptions from the NAEI.

Absorbent addition - SO_2 emissions

As no cost estimates specific to the lime sector were available in the BREF (2010), the cement cost estimates have been adjusted on the basis of exhaust dry gas volumes per unit of capacity and updated to current prices.

No kilns are currently using or are known to be planning to implement absorbent addition as BAU in the future. The maximum potential further uptake of this measure has been estimated on the basis of SO_2 emissions at kilns which are assumed not to have installed wet scrubbers under BAU in 2025/2030; this information is based on site-specific assumptions from the NAEI.

PM emissions

See above for cement.

A10.4 Summary of measures

Table A10.8 summarises the potential uptake and associated costs of each beyond BAU abatement technology for the cement and lime sectors. The costs are based on the average cost of each abatement technology. Table A10.9 summarises the assumed abatement efficiency for each measure as well as the estimated emission reductions.

Table A10.8 Summary of beyond BAU abatement measures for the cement and lime sectors for 2025 and 2030 [1]

Abatement measure	Future uptake of measure (%)		Operating life (years)	Capital Costs (£k, 2011 prices)		Annual operating costs (£k, 2011 prices)		Total annualised costs (£kpa, 2011 prices)	
	2025	2030		2025	2030	2025	2030	2025	2030
Cement									
SNCR (Low)	14%	14%	15	1,142	1,142	223	223	323	323
SNCR (High)	12%	12%	15	0	0	1,150	1,150	1,150	1,150
Wet Scrubber	52%	52%	15	84,288	84,288	8,191	8,191	15,510	15,510
Absorbent Addition	31%	31%	15	728	728	728	728	791	791
Lime									
Wet Scrubber (coal)[2]	76%	76%	15	66,957	66,957	6,507	6,507	12,321	12,321
Wet Scrubber (coke) [2]	100%	100%	15	5,869	5,869	570	570	1,080	1,080
Absorbent Addition (coal) [2]	76%	76%	15	969	969	969	969	1,053	1,053
Absorbent Addition (coke)[2]	100%	100%	15	85	85	85	85	92	92
SNCR (Low)	78%	78%	15	327	327	12	12	41	41
SNCR (High)	16%	16%	15	0	0	42	42	42	42

Note 1: The costs presented here are the average costs for each abatement measure (in case a measure was given a range of costs. A discount rate of 3.5% is considered in the analysis.

Note 2: The costs and impacts of application of these measures have been calculated separately for the coal and coke emission sources in the NAEI. If considering real life uptake then the measure should be combined for both fuels.

Table A10.9 Summary of beyond BAU abatement measures efficiency for other industrial combustion sector

Abatement measure	Emission reduction efficiency (%)						Reduction in 2025 emissions (kt)						Reduction in 2030 emissions (kt)					
	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3
Cement																		
SNCR (Low)	33%					0%	0.33						0.33					
SNCR (High)	38%					-61%	0.30						0.30					
Wet Scrubber		90%	50%	50%				1.68	0.04	0.08				1.68	0.04	0.08		
Absorbent Addition		70%						0.78						0.78				
Lime																		
Wet Scrubber (coal)[2]		90%	50%	50%				0.45	0.00	0.00				0.42	0.00	0.00		
Wet Scrubber (coke)[2]		90%	50%	50%				1.66	0.00	0.00				1.85	0.00	0.00		
Absorbent Addition (coal)[2]		70%						0.35						0.33				
Absorbent Addition (coke)[2]		70%						1.29						1.44				
SNCR (Low)	33%						0.07						0.06					
SNCR (High)	38%						0.01						0.01					

A10.5 References

1. Natural Environment Research Council, (February 2008) ‘British Geological Survey: Mineral Planning Factsheet – Cement’. Downloaded 31st May 2012 from: http://www.bgs.ac.uk/mineralsuk/

2. Communication with the Mineral Products Association on the 22nd April 2009

3. Environment Agency (2009): ‘Statutory Permit Review – Cement & Lime Sector: Phase 1 Sector performance review’.

4. Environment Agency (2010), ‘Statutory Permit Review – Cement and Lime Sector: Phase 2 Permit Review Plan’.

5. Discussion with the Environment Agency’s ‘Waste Incineration and Cement, Lime and Minerals Technical Adviser’ on the 17th April 2012.

6. European Commission (May 2010): Reference Document on Best Available Techniques in the Cement, Lime and Magnesium Oxide Manufacturing Industries. Downloaded 12th April 2012 from: http://eippcb.jrc.es/reference/BREF/clm_bref_0510.pdf

7. The Environment Agency, (November 2010), ‘How to comply with your environmental permit. Additional guidance for: The cement industry (EPR 3.01a). Available for download on the 11th April 2012 from: http://www.environment-agency.gov.uk/static/documents/Business/How_to_Comply_-_Cement_EPR3_01a.pdf

8. The Environment Agency, (November 2010), ‘How to comply with your environmental permit. Additional guidance for: The lime industry (EPR 3.01b). Available for download on the 11th April 2012 from: http://www.environment-agency.gov.uk/static/documents/Business/How_to_Comply_-_Lime_EPR3_01b.pdf

9. European Commission, (24 September 1996), ‘Council Directive 96/61/EC of 24 September 1996 concerning integrated pollution prevention and control’. Available for download on the 12th April 2012 from: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:1996:257:0026:0040:EN:PDF

10. European Commission, (4 December 2000), ‘Directive 2000/76/EC of the European Parliament and of the council of 4 December 2000 on the incineration of waste’. Available for download on the 12th April 2012 from: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2000:332:0091:0111:EN:PDF

11. European Commission, (24 November 2010), ‘Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control) (Recast)’. Available for download on the 12th April 2012 from: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:334:0017:0119:EN:PDF

12. Department for Environment Food and Rural Affairs (Defra) website - Industrial Emissions Directive: http://www.defra.gov.uk/environment/quality/industrial/eu-international/industrial-emissions-directive/

13. European Environmental Bureau, (14th July 2011), 'New Features under the Industrial Emissions Directive'. Available for download on the 17th April 2012 from: http://www.eeb.org/?LinkServID=290B7936-ADF0-4AD8-D16350AB49EE7DFC&showMeta=0

A11. Contents

A11.Glass

A11.1 Sector profile

Container glass accounts for approximately 60% of the glass produced in the UK. In 2010, there were six manufacturers in the UK producing container glass, which includes items such as bottles and jars. Flat glass is the next largest type of glass production, with three companies producing flat glass in the UK. It is predominately used for windows and in vehicles.

Mineral wool accounts for approximately 10% of the total glass industry, and includes both glass wool and stone wool, typically used as insulating materials. Five installations in the UK are reported in BREF (EC, 2012) to have been producing mineral wool in 2008.

Glass production is a significant source of PM emissions, accounting for approximately 1.5% of the UK PM10 and PM2.5 emissions in the NAEI projections. Particulate emissions arise from the furnaces and melting stages of the glass production process. Furnaces are typically gas or oil fired, and common types are end-fired, cross-fired and recuperative furnaces with heat recovery. Downstream surface treatments can also give rise to PM emissions. For glass wool, PM emissions also arise from the forming area, where a binder is applied to the fibres. Fugitive PM emissions also arise from storage and preparation of the fibre coatings, and handling and packaging activities.

A11.2 Business as usual policies and abatement measures

Glass manufacturing sites are typically regulated under the LA-IPPC regime as A2 sites. The LA-IPPC guidance gives BAT as having either an electrostatic precipitator or bag filter in place, with a particulate limit of 30 mg/m^3. Unabated dust emissions for container glass are approximately 150 mg/m^3, while BREF reports a mean value of 10 mg/m^3 for abated PM emissions. On this basis, it is assumed that regulated UK flat glass and container glass plants already have some abatement measures in place.

Most modern glass wool installations have dust emissions less than 5 mg/m^3 as filter systems are fitted. Electrostatic precipitators and bag filters are widely used in the sector according to BREF and the LA-IPPC permit guidance, which lists these as BAT. For electrostatic precipitators, emission concentrations of 5 – 10 m/m^3 can be achieved, and 0.5 – 5 mg/m^3 for bag filters.

IPPC will be replaced by the Industrial Emissions Directive, and will apply to existing sites from 2014. Current BAT will become a requirement for the permits, so it is expected that bag filters or electrostatic precipitators will be mandatory for glass wool installations.

A11.3 Beyond business as usual potential abatement measures

11.3.1 Oxy-fuel fired cullet and batch pre-heaters

PM

Oxy-fuel fired furnaces are not widely in place, with only 8 out of 248 furnaces in a 2005 EU survey (FEVE, 2009 cited in EC, 2012) being of this type. These furnaces use an increase in the concentration of oxygen to improve the combustion process. The existing approach of cullet and batch preheating is currently being developed for use in conjunction with oxy-fuel furnaces, which is listed as an emerging technique in BREF (EC, 2012). Although this process should improve glass productivity and quality and reduce NOx and particulate emissions, BREF reports that high costs are still a barrier in the sector. The furnaces produce flue gases at high temperatures of 1400^{o}C, which currently must be cooled to 500 – 600 ^{o}C for standard cullet and batch pre-heaters. The economics improves if more energy can be recovered from the hot exhaust fumes. The advanced pre-heaters discussed in BREF can undergo cullet and batch pre-heating at1200 – 1400 ^{o}C, so do not require this cooling.

Reduction in PM, NOx and CO_2 of 15 – 30% is reported to occur with this advanced oxy-fuel technology and pre-heating. As of 2010, there were two projects developing this technology, the PRECIOUS-project and PRAXAIR-BCP, but no indicative costs were available for these projects so this technology could not be included as a BBAU measure.

11.3.2 Charged cloud scrubber

PM

Charged cloud scrubbers consist of a chamber containing charged droplets of water, which remove particulates and waste gases as they pass through the cloud. The waste particles aggregate at the bottom of the chamber and can be removed and disposed of. In addition to removing particulates, charged cloud scrubbers are also reported to remove SO_2 and NH_3. Abatement for PM was reported as a reduction from 410 mg/Nm^3 to 23 mg/Nm^3, and a reduction of 770 mg/Nm^3 to 1 mg/Nm^3 for SO_2. No cost data was available in BREF or in the literature review, so this has not been included as a measure.

11.3.3 Ceramic filter

PM

Ceramic filters are not yet BAT and not reported to be widely used yet, so it is assumed that they will not be in place in 2025/2030 under BAU activities. BREF reports that concentrations of <2mg/m^3 of PM are reached when operating correctly, which is a reduction on the BAT measures currently in place. This would give an abatement efficiency of 80% based on a reduction from the average BAU PM emissions of 10 mg/m^3 reported in BREF for flat and container glass, and 60% efficiency for the glass wool PM reduction from 5 mg/m^3. An uptake rate of 90%

is estimated for each glass type to allow for plant-specific factors that may prevent ceramic filters being fitted in some cases.

No costs are provided specifically for the glass sector. Capital costs are based on the cost of ceramic filters to the Aluminium sector listed in BREF of €$_{1999}$ 30 / tonne production. This gives capital expense of €$_{1999}$ 23 million for flat glass, €$_{1999}$ 68 million for container glass and €$_{1999}$ 7.2 million for glass wool. An estimated cost per gram PM10 abated has been developed from the operating costs for fabric filters in the Iron & Steel sector. It is assumed that the technology for filters for PM abatement in both sectors is broadly comparable, such that an indicative cost can be produced. The cost per tonne of sinter was used in conjunction with the annual sinter production and tonnes of PM abated in a year to calculate a cost per gram PM abated. This was then combined with the grams of PM abated for flat glass, container glass and glass wool. Operating costs were €$_{1996}$ 863,000, €$_{1996}$ 995,000 and €$_{1996}$ 114,000, respectively.

A11.4 Summary of measures and costs

Table A11.1 summarises the estimated cost of each abatement technology for the glass sector. The costs in the summary table are based on the average cost of each abatement technology. The range of costs were summarised in Section A11.3 for dust abatement measures, and Table A11.2 presents the reduction efficiency of the abatement measures and the associated reduction in emissions.

Table A11.1 Summary of beyond BAU abatement measures for the Glass sector (container glass, flat glass & glass wool) for 2025 and 2030 [1]

Abatement measure	Future uptake of measure (%)		Operating life (years)	Capital Costs (£k, 2011 prices)		Annual operating costs (£k, 2011 prices)		Total annualised costs (£kpa, 2011 prices)	
	2025	2030		2025	2030	2025	2030	2025	2030
Ceramic filter (container glass)	90%	90%	15	63,617	63,617	966	942	6,489	6,465
Ceramic filter (flat glass)	90%	90%	15	32,902	32,902	838	817	3,695	3,674
Ceramic filter (glass wool)	90%	90%	15	6,790	6,790	111	108	700	697

Note 1: The costs presented here are the average costs for each abatement measure (in case a measure was given a range of costs. A discount rate of 3.5% is considered in the analysis.

Table A11.2 Summary of beyond BAU abatement measures efficiency for Glass sector

Abatement measure	Emission reduction efficiency (%)						Reduction in 2025 emissions (kt)						Reduction in 2030 emissions (kt)					
	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3
Ceramic filter (container glass)			80%	80%					0.52	0.56					0.51	0.54		
Ceramic filter (flat glass)			80%	80%					0.45	0.48					0.44	0.47		
Ceramic filter (glass wool)			60%	60%					0.06	0.06					0.06	0.06		

A11.5 References

1. EC (2012) “Best Available Techniques (BAT) Reference Document for the Manufacture of Glass”
2. British Glass (2001) “Industry Overview” http://www.britglass.org.uk/industry
3. Environment Agency (October 2001) “Sector Guidance Note IPPC S3.03 Integrated Pollution Prevention and Control (IPPC) Guidance for the Glass Manufacturing Sector (A1 processes)”
4. Environment Agency (October 2006) “Sector Guidance Note IPPC SG 2 Integrated Pollution Prevention and Control (IPPC) Secretary of State’s Guidance for A2 Activities in the Glassmaking Sector”

A12. Contents

A12.Brick Manufacture

A12.1 Sector profile

Table A12.1 presents the emissions for brick manufacture developed by AEA, based on DECC's UEP43 forecasts and the 2009 baseline National Atmospheric Emission Inventory (NAEI).

Table A12.1 Emissions for brick manufacture for 2025 and 2030 (no change between years)

SnapID	Source Name	Activity Name	Emissions (kt)					
			NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3
30319	Brick manufacture - Fletton	Fletton bricks	-	4.0	0.1	0.2	0.8	-
30319	Brick manufacture - non Fletton	Non-Fletton bricks	-	-	0.7	1.1	-	-

As shown by the emission projections, the key source of PM emissions is non-Fletton brick manufacture, whilst the key source of SO_2 emissions is Fletton brick manufacture, hence the analysis for the brick manufacture sector has focused on these emission sources. The NAEI data suggests that this sector contributes to 1.7% of UK SO_2 emissions in 2030. Whilst the emission projections suggest that Fletton brick manufacture contributes to VOC and PM emissions, this is not considered significant (<1% of total emissions), therefore measures for VOC and PM control from these sources have not been investigated.

There are around 134 brick manufacturing works in the UK (EC, 2007). Only two[1] of these are thought to be 'Fletton' brick manufacturing process, i.e. manufactured from Lower Oxford Clay, which contains significant levels of sulphur-containing organic material. The remaining plants are all 'non-Fletton' types, i.e. they use different types of clay.

PM emissions can be produced at several stages during the handling, transporting and processing of raw materials, usually clay, and also during the firing stage of the product in a kiln. For 'non Fletton' brick manufacturing works, it is suggested that 67% of PM emissions are from processing the dry material (uncontrolled), whilst the remaining is from the natural gas-fired kiln (AEA, 2004).

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[1] This is because one of the three Fletton brick manufacturing works has closed in recent years. BCC has indicated that this site was primarily coal-fired. This site represented 31% of total product output in 2005 (Personal Communication with the British Ceramic Confederation, 12th June 2008)

SO_2 emissions can be produced during the firing stage, and are closely related to both the sulphur content of the fuel (which is significant for solid fuels and fuel oils) and the raw material (which is more relevant to ‘Fletton’ brick works due to the significant levels of sulphur-containing organic material) (EC, 2007).

A12.2 Business as usual policies and abatement techniques

Brick manufacturing must comply with the IPPC Directive (due to be superceded by the Industrial Emissions Directive). Under IPPC, the two Fletton brick manufacturing works fall within Part A1 processes, while most of the remaining processes fall within Part A2 processes.

Under this Directive, the compliance date for existing installations to operate in accordance with BAT-based permit conditions was 30 October 2007. Reducing the emissions of gaseous compounds (i.e. HF, HCl, SO_X) from the flue gases of kiln firing processes by addition of calcium rich additives, if the quality of the end-product is not affected, is considered BAT.

A sector guidance note (SG7)[2] has been developed for the A2 Ceramics Sector Including Heavy Clay, Refractories, Calcining Clay and Whiteware that gives statutory guidance on the integrated pollution control standards appropriate for new and existing A2 installations in the Ceramics sector. A process guidance note (PG 3/2) [3] has also been developed for the Manufacture of Heavy Clay Goods and Refractory Goods to give guidance on the conditions appropriate for the control of emissions into the air from the manufacture of heavy clay goods and refractory goods processes/installations. The sector and process guidance notes contain emission limits for Part A2 and Part B processes for various pollutants, more specifically for particulate matter emission limits are 100 mg/m^3 or 50 mg/m^3 depending on the activity. BAT is discussed in section 3 of the sector guidance note and in section 6 of the process guidance note.

During discussion with BCC[4] it was mentioned that it is expected that operators have in place a number of control measures described in the guidance note, e.g. bag filters are used extensively – not at kilns but other parts of the site – for instance dust from the grinding plant is extracted to bag filters, water sprays are used at long term stocking areas, enclosure of dusty operations is in place, electrostatic precipitators (although not common) are also used. Testing of exhaust gases from kilns has rarely showed concentrations higher than 10 mg/m^3 for particulates. IPPC has concentrated focus on reducing emissions of particulate matter from the whole site, especially from the raw material preparation that is considered the most significant source for these emissions.

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[2] http://www.defra.gov.uk/environment/ppc/localauth/pubs/guidance/notes/sgnotes/pdf/sg7-07.pdf

[3] http://www.defra.gov.uk/environment/ppc/localauth/pubs/guidance/notes/pgnotes/pdf/minpg3-2.pdf

[4] Personal Communication with the British Ceramic Confederation, 12th June 2008

End of pipe abatement measures for reducing SO_2 emissions, for instance wet scrubbers, are not in place at the Fletton sites.[5] Discussions with the BCC have also indicated that the remaining two sites are primarily gas-fired (but with capability of coal firing retained).[6]

A12.3 Beyond business as usual

12.3.1 Abatement techniques

The BREF document describes various abatement measures and emerging technologies (EC, 2007) that could be considered as beyond BAU measures, if these are not implemented under IPPC.

Emissions from kilns are naturally low, whilst fugitive emissions are generally expected to be captured and abated. As described above, an operator may choose any abatement measure in order to comply with local air quality regulations and environmental standards, hence it is not possible to differentiate which dust control options are more commonly used (under BAU) in this sector. Although measures may be in place, it is likely that additional abatement for diffuse dust emissions is possible. Therefore a general dust control abatement improvement measure is applied as beyond BAU for this sector. Further information is provided in the section on fugitive PM emissions.

Currently, the majority of SO_2 emissions from this sector are process emissions due to the sulphur present in the raw materials, and not from fuel combustion. Overall, the brick manufacturing industry uses 85% gas, 13% electricity and 2% of other fuels such as coal, renewables and oil.[4] Therefore, fuel switching has not been considered as a potential beyond BAU measure for this sector.

There are two end of pipe abatement techniques in the sector BREF which have the potential to significantly reduce SO_2 emissions; dry or wet scrubbers. Each of these is an end of pipe measure which could be fitted to the kiln flue pipe. The BREF document recommends dry scrubbing as BAT, and although details are provided for wet scrubbing it is noted that the installation and operating costs are higher and the operating life is shorter. Therefore, wet scrubbing would only be considered for special circumstances and has been excluded from this assessment.

Dry scrubbers consist of a sorbent (e.g. calcium hydroxide) being injected into the kiln flue pipe where it reacts with the acid gases (including SO_2). The reagent is then removed from the exhaust by a bag filter. This process does produce a large amount of waste and requires electric fans to draw the exhaust through the filter.

12.3.2 Methodology/assumptions

For this assessment it is assumed that dry scrubbers are fitted to the two remaining Fletton brick works, in order to achieve SO_2 reductions for the sector.

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[5] Personal Communication with the British Ceramic Confederation, 11th July 2008

[6] Personal Communication with the British Ceramic Confederation, 12th September 2008

A wide range of costs are presented in the BREF, to provide a rough investment guideline for typical installations. These costs, as presented in Table A12.2, are for the whole of the ceramics sector, not specifically for brickworks.

Table A12.2 Dry scrubber costs

	Cost (€)
Investment	80,000 – 1,000,000
Annual operating cost (maintenance + sorbent cost +electricity[a])	20,000 – 60,000

Notes: a) kWh/day quoted – 330 days and 7p/kWh assumed.

Reference: European Commission, 2007

Discussion with BCC[7] indicates that the operator has previously investigated both dry and wet scrubbers for installation at the two adjacent Fletton brickworks, to submit to the Environment Agency whilst negotiating their PPC permit. The conclusion was both techniques are unproven for Fletton kilns, and although there would be a significant reduction in SO_2 emissions, this would be at a cost of £57-62 million with an annual operating cost of £6-10 million. The two sites are thought to have five stacks (Peterborough CC, 2006) so these costs relate to £12 million installation costs and £1.8 million operating costs per unit. These costs are significantly higher than the upper ranges quoted in the BREF however there is insufficient transparency to verify the costs provided by industry. The costs are comparable to the cost for fitting a scrubber to a cement kiln (Appendix 6). The BCC costs have been applied on the basis that the BREF costs are for the whole, diverse ceramics sector; Fletton bricks differ from other ceramics because the type of clay used has higher sulphur content than normal and their production appears to be unique to these two sites.

A standard fugitive PM control measure is applied for fugitive PM emissions from non-Fletton brick manufacturing. See “Fugitive emissions of PM” chapter for a detailed description of the measure and cost analysis.

12.3.3 Summary of measures and costs

Table A12.3 summarises the estimated cost of each abatement technology for the bricks sector based on the average cost of each abatement technology. The range of costs were summarised in Table A12.22 and Table A12.3 presents the reduction efficiency of the abatement measures and the associated reduction in emissions.

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[7] Personal Communication with the British Ceramic Confederation, 11th June 2009

Table A12.3 Summary of beyond BAU abatement measures for the Fletton bricks sector (2025 and 2030)

Abatement measure	Future uptake of measure (%)		Operating life (years)	Capital Costs (£k, 2011 prices)		Annual operating costs (£k, 2011 prices)		Total annualised costs (£kpa, 2011 prices)	
	2025	2030		2025	2030	2025	2030	2025	2030
Dry scrubber	100	100	15	59,676	59,676	8,992	8,992	14,174	14,174

1: Assumed operating life of 15 years has been assumed throughout as no other information has been identified

2: Prices have been updated to 2011 using the RPI

Table A12.4 Summary of beyond BAU abatement measures efficiency for Fletton bricks

Abatement measure	Emission reduction efficiency (%)						Reduction in 2025 emissions (kt)						Reduction in 2030 emissions (kt)					
	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3
Dry scrubber		80	99	99				3.23	0.19	0.12				3.23	0.19	0.12		

A12.4 References

1. AEA (2004), Emission factors programme, Task 9 – Review of Particulate Matter Emissions from Industrial Processes, A report prepared for the Department for Environment, Food and Rural Affairs; the National Assembly of Wales: the Scottish Executive; and the Department of Environment in Northern Ireland, June 2004.

2. EC (2007), European Commission, 2007, Integrated Pollution Prevention and Control (IPPC) Reference Document on Best Available Techniques in the Ceramic Manufacturing Industry, August 2007.

3. Peterborough County Council (2006), Detailed Assessment of Sulphur Dioxide, September 2006.

A13. Contents

A13.Wood Products Manufacture

A13.1 Sector Profile

The table below presents the emissions for the Wood Products Manufacturing sector developed by AEA, based on the DECC UEP43 forecasts and 2009 NAEI baseline.

Table A13.1 Emissions for Wood Products manufacture sector for 2030

Source Name	Activity Name	Emissions (kt)			Contribution to total emissions (%)		
		$PM_{2.5}$	PM_{10}	VOC	$PM_{2.5}$	PM_{10}	VOC
Wood products manufacture	Wood products production	0.98	1.18	0.22	2.0%	1.1%	0.0%

Particulate matter emissions can be produced at several stages during the handling, transporting and processing of wood. Sawmill operations may use controlled incineration to dispose of wood waste which may also be a source of particulate matter. Secondary processing, where timber may be dried in kilns and undergoes size reduction operations, is considered the main source of finer particulate matter ($PM_{2.5}$ and PM_{10}) within the sector, and therefore abatement for such processes is the main focus of this chapter.

There has been no focus on VOC emissions because emissions in 2030 are forecast to be only 0.22kt (around 0.03% of total VOC emissions in 2030).

There were 8,397 wood products manufacturing enterprises in the UK in 2006[1], ranging from sawmilling, planning and pressure treatment, to the production of wood-based panels and boards, carpentry, joinery, pallets and packaging furniture. The vast majority of companies are SMEs, with only a few large groups, typically in the softwood sawmill and panel sectors. A wide range of products are processed by the primary and secondary transformation of wood and used in many applications, from building components to furniture parts and packaging.

The sector can be divided into two sub-sectors consisting of the basic sawmilling that produces inputs into the manufacturing processes and the final products manufacture and assembly. In some plants, the entire process is integrated with inputs of wood at one end leading to finished assembled products at the other. More often sawmills produce sawn timber for input to other plants or for sale directly to the market. Manufacturing plants purchase sawn timber and board products to build final products, such as furniture.

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[1] Office of National Statistics (2006), Annual Business Enquiry

The main sources of particulate matter within the sector include:

- Machining operations, for example, sawing, drilling, sanding, shaping, turning and planing;
- Transfer of wood particles created by sawing/machining operations, for example into holding areas or vehicles;
- Size reduction operations, for example, granulation of wood offcuts;
- Drying and pressing operations in the wood-based panel sector;
- Stockpiles, for example, woodchips;
- Arrestment plant outlets, for example, cyclones and bag filtration units;
- Bagging of sawdust/woodchips form arrestment plant outlet points;
- Skips or containers where sawdust/woodchips are stored on site, for example, prior to removal from site.

A13.2 Business as Usual Policies and Abatement Techniques

Pollution Prevention and Control (PPC)

The main policy driver for controlling air quality impacts of the sector is the Pollution Prevention and Control Act 1999, which was superseded by the Environmental Permitting (England and Wales) Regulations 2007.

A number of wood product manufacturing installations in the UK are subject to PPC requirements as a Part B process under the Environmental Permitting Regulations and IPPC Regulations in Scotland and Northern Ireland as follows:

Manufacturing products wholly or mainly of wood at any works if the activity involves the sawing, drilling, sanding, shaping, turning of wood and the throughput of the works in any period of 12 months is likely to be more than

(i) 10,000 cubic metres in the case of works at which wood is only sawed, or wood is sawed and subjected to excluded activities, or

(ii) 1,000 cubic metres in any other case

The wood-based panel sector is covered separately as a Part A(2) process under PPC as follows:

Manufacturing wood particleboard, oriented strand board, wood fibreboard, plywood, cement bonded particleboard or any other composite wood based board

The restrictions imposed by these policies have led to a number of abatement measures already being applied to the sector.

All wood-based panel installations in the UK are regulated under IPPC. It is understood that very few sawmills and furniture operations are covered under PPC, however the Environmental Protection (Prescribed Processes and Substances) Regulations 1991 apply to the sector for emissions to air.

PPC provides limits on particulate matter emissions and sets out conditions to control these emissions. This may include site investigation and testing to identify sources of PM_{10} and $PM_{2.5}$ originating from the process. The operator may be required to undertake an assessment of PM_{10} and $PM_{2.5}$ emissions and the effect on the surrounding area and include details of measures available to reduce emissions where Air Quality Standards may be exceeded.

Various wood processes are covered under the Solvent Emissions Directive (SED) as implemented via PPC (and now part of the Industrial Emissions Directive). For example, in the furniture manufacturing sector activities, including the use of varnishes, paints and veneers, will give rise to VOC emissions and some of these industries may come under the SED. Coating activities are in the scope of the SED[2]. Such activities are covered under 'Industrial Coatings – Wood Coatings' of this report and are therefore not addressed here.

In the UK, wet electrostatic precipitators (WESPs) and/or scrubbers are widely used in the wood-based panel industry to abate point source emissions from the process. This abatement technology has over 99% reduction efficiency. The WESP operates by using high voltage electrical current to impart an electrical charge to particulate matter passing through the device and then collecting the charged particles on collection plates. The collection plates are periodically rapped or vibrated to dislodge the particulates to a hopper. Their performance is affected by the electrical properties of the dust and collection efficiency is markedly lower for finer particles (<1um). The choice of scrubber design will depend on whether the control of gaseous or particulates pollutants is more important. Wet scrubbers are less efficient at collecting fine particles.

Within sawmilling and wood products manufacturing processes, particulate matter is generated during sawing, machining and sanding operations. Two types of abatement technique commonly used in the industry are fabric (bag) filters and cyclones. In most circumstances, fabric filters of an appropriate specification or a combination of cyclones in line with fabric filters should be fitted in preference to cyclones alone as they are significantly more efficient for the control of emissions. As the moisture content of the material processed increases, fabric filters will begin to clog, reducing both efficiency and lifespan, and requires more maintenance. Fabric filters are very efficient even for fine particulates (<1um). Cyclones are suitable abatement equipment for larger/coarser particulates and are used mainly for smaller (Part B) processes. For particles smaller then 10um and particularly below 2.5um their efficiency is substantially poorer than ESPs and bag filters. They would only be used as a first stage abatement device for larger industrial (Part A) processes.

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[2] Council Directive 1999/13/EC of 11 March 1999 on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain activities and installations.

Particulate matter that may become wind-entrained should be contained and diverted to suitable abatement techniques. This can be achieved by employing measures such as windbreaks, spraying or binders (for outdoor stockpiles). Good housekeeping practices are also employed to minimise particulate matter generation.

Process Guidance Note 6/2 (04) provide indications on BAT for the control of particulate matter releases from the manufacture of timber and wood-based products.

Table A1.4 provides a summary of BAT that can be used to control emissions from secondary processes in order to meet emission limits.

Table A13.4 Summary of control techniques considered to be BAT for the sector for controlling PM emissions

Release source	Control Technique
Whole train of process equipment	Containment policy i.e. containment at source (control of fugitive emissions)
Machining operations e.g. size reduction including granulation of wood cut offs	Arrestment plant - bag filters (usually preferred) - cyclones
Dryers, presses, other sources (panel sector)	Wet electrostatic precipitator (WESP)
Wood residue incineration and combustion in boilers	Wood waste fuel should be of low moisture content Store wet and dry waste wood separately Use of cyclones, bag filters and/or electrostatic precipitators, and/or scrubbers to control particulate emissions

Sector Guidance Note SG1 provides guidance on BAT for the wood panel sector. Emission limits have been set for particulate matter and are only applicable to contained emissions exhausted to the atmosphere. Table A1.5 details emission limits for particulate matter for the sector.

Table A13.5 Summary of contained emission limits for particulate matter under IPPC

Pollutant	Source	Emission limit (mg/m3)
Particulate matter	All contained sources other than wood dryers and Medium Density Fibreboard (MDF) production	50
	Medium Density Fibreboard (MDF) production – all contained sources	20
	Wood dryers	20

Discussions with trade associations indicated that many of these prevention, minimisation and control measures for finer particulate matter are already applied throughout the wood product manufacturing sector, however the percentage of application is unknown.

A13.3 Potential beyond BAU measures

13.3.1 Abatement Techniques

The trade associations are not aware of any further feasible abatement measures available for this sector beyond those already applied (described in previous section). It can be concluded that particulate matter emissions from secondary sources are already abated by efficient abatement techniques and therefore there appears to be little potential for further abatement measures.

The percentage uptake of existing abatement options for the sector is not known. However, it can be estimated that that there is 95-100% uptake of existing abatement options within the wood-based panel sector, based on communication with the Wood Panel Industries Federation, in May 2008. The trade associations indicated that uptake was high across the whole wood products manufacturing sector, however there may be scope for further uptake of existing options.

The trade associations identified BAU measures such as wet electrostatic precipitators (in the wood-based panel sector) bag filters and cyclones. Some beyond BAU options for this sector are energy efficiency measures (as identified in the sector guidance), such as heat recovery and optimised efficiency measures for combustion plant. Further beyond BAU measures for the sector include use of combined heat and power (CHP) and generation of energy from waste.

CHP

Combined heat and power is an option available, but prices are currently inhibiting. The potential uptake of this measure is uncertain and it was not possible to get an indication of the associated costs for the implementation of this measure.

Energy from waste wood

The use of waste wood as a fuel source is common across the sector. Discussions with the trade association indicated that there are increasing difficulties for the industry (particularly the panel sector) in sourcing uncontaminated clean wood, as there is such high demand for this across the sector and other sectors. The Waste Incineration Directive (WID) introduced strict controls and minimum technical standards for waste incinerators and co-incinerators and the incineration of wood waste that has been treated with wood preservatives or coatings containing halogenated compounds or heavy metals is most likely to be covered by WID.

13.3.2 Summary of Measures and Costs

No further feasible abatement measures were identified for this sector. There appears to be little scope for further abatement measures within the wood products manufacturing sector, as particulate matter emissions are already abated by efficient abatement techniques. Therefore, no additional abatement measures have been developed.

A13.4 References

1. Entec (2006), Development of $PM_{2.5}$ Cost Curve, A report for Defra, March 2006
2. Defra Air Quality Expert Group, Particulate Matter in the UK, 2005
3. Defra (2004), Process Guidance Note 6/2 (04) for the Manufacture of Timber an Wood-Based Products, June 2004
4. Defra (2006), Sector Guidance Note IPPC SG1 for A2 Particleboard, Oriented Strand Board and Dry Process Fibreboard Sector, September 2006
5. International Finance Corporation World Bank Group (2007), Environmental, Health and Safety Guidelines for Sawmilling and Manufactured Wood Products, April 2007
6. IIASA (2006), Interim Report IR-06-011 - The potential for further control of emissions of fine particulate matter in Europe, May 2006
7. CEI-Bois, European Wood Factsheet for the Woodworking Industry
8. UK Forest Products Association (UKFPA), Personal communication, May 2008
9. HSE, Personal communication, May 2008
10. Local Authority regulating Part A2 installation, Personal communication, May 2008
11. Wood Panel Industries Federation, Personal communication, May 2008
12. British Woodworking Federation, Personal Communication, April 2009
13. British Furniture Manufacturing Association, Personal Communication, April 2009

A14. Contents

A14.Fugitive Emissions of PM

A14.1 Sector profile

Emissions of PM arising from quarrying, brick manufacturing (non-Fletton), stockpiles in integrated steelworks, asphalt manufacturing, and “Part B” industrial processes, coke production[1], construction and cement and concrete batching are significant (>0.1% of UK total), but are dispersed and less well understood than other emission sources. The emission projections for these sources are recognised to have high uncertainty (AEA, 2012). Best practise guidance and discussions with various stakeholders (Entec, 2011) suggest that good house keeping and various physical measures (e.g. screening against wind, water spraying) are generally implemented. However, there is uncertainty over the extent of uptake of such measures and to what degree additional or enhanced dust control measures could be implemented.

Table A14.1 Fugitive emissions of PM from key sectors, 2030

Sector	PM_{10} (kt)	PM_{10} (% of UK total)[1]	$PM_{2.5}$ (kt)	$PM_{2.5}$ (% of UK total)[1]
0_Quarrying_Aggregates	6.94	6.6%	2.01	4.0%
0_Other industry - part B processes_Process emission	2.94	2.8%	1.47	2.9%
1A4ai_Integrated steelworks - stockpiles_Iron production	2.22	2.1%	0.64	1.3%
1A3dii_Brick manufacture - non Fletton_Non-Fletton bricks	1.04	1.0%	0.67	1.3%
0_Construction_Construction	0.71	0.7%	0.22	0.4%
2A6 Other industry – asphalt manufacture	0.41	0.4%	0.20	0.4%
1A1c Coke production – coke produced	0.28	0.3%	0.07	0.1%
Total	14.54	13.8%	5.28	10.5%

1: Excluding road transport

A14.2 Beyond business as usual potential abatement measures

Entec (2004, 2006) identified a number of abatement measures for the control of dust emissions from quarrying. These measures included the following:

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[1] Although it is not 100% sure whether the PM emissions from “coke production” are fugitive PM emissions, it has been included in the analysis.

- Conveyors: (1) cleaning with belt scrapers; (2) enclosure; (3) minimise drop heights; and (4) water sprays;
- Crushing and screening: (1) enclosure, extraction and treatment; and (2) water sprays;
- Haulage: (1) improve road design; (2) pave road restrictions; (3) speed restrictions; (4) shield roads from wind; (5) use dust suppressant chemicals; and (6) water road surfaces;
- Mineral extraction: (1) minimise unnecessary handling; (2) reduce drop heights; (3) shield from wind; and (4) water sprays; and
- Mounds and stockpiles: (1) chemical dust suppressants; (2) enclosure; (3) shield from wind; and (4) water sprays.

In addition to the costs and PM abatement efficiency rates of individual abatement measures, Entec (2004, 2006) also identified BAU and BBAU rates for 2020. In most cases, the BAU uptake rate was relatively high, ranging from 75% to 95%, suggesting that many of these practices that reduce PM emissions are indeed being practiced by quarry operators.

Considering that PM abatement measures similar to these can be implemented in a similar manner in other sectors with fugitive PM emissions, a "standard fugitive PM control measure" is developed to be applied to all activities leading to significant fugitive PM emissions. Emission reduction-based weighting has been applied to the individual annualised investment costs of the PM control measures for quarrying to estimate a weighted average of investment costs. The investment costs are then divided by total reduction in PM emissions in order to arrive at 4,381 $£_{2011}$ / tonne of PM abated. Similarly, emission reduction-based weighting has been used to estimate weighted average of emission reduction efficiency of 9.5% to be used for the standard fugitive PM control measure. Because investment costs and abatement efficiency rates of the fugitive PM abatement measures in the quarrying sector were the same for PM_{10} and $PM_{2.5}$, the emission reduction-based weighting approach to estimate investment costs, abatement efficiency and uptake level for this standard fugitive PM control measure provides consistent results when using either PM_{10} or $PM_{2.5}$.

A14.3 Summary of measures and costs

Table A14.2 summarises the estimated cost of each abatement technology for the other combustion sector. The costs in the summary table are based on the average cost of each abatement technology. Table A14.3 presents the reduction efficiency of the abatement measures and the associated reduction in emissions.

Table A14.2 Summary of beyond BAU abatement measures for the combined PM measure for 2025 and 2030 [1]

Abatement measure	Future uptake of measure (%)		Operating life (years)	Capital Costs (£k, 2011 prices)		Annual operating costs (£k, 2011 prices)		Total annualised costs (£kpa, 2011 prices)	
	2025	2030		2025	2030	2025	2030	2025	2030
Standard fugitive PM control measure – Quarrying	100%	100%	10	N/A	N/A	N/A	N/A	781	835
Standard fugitive PM control measure – brick manufacture (non-Fletton)	100%	100%	10	N/A	N/A	N/A	N/A	283	276
Standard fugitive PM control measure – integrated steel works, stockpiles	100%	100%	10	N/A	N/A	N/A	N/A	267	267
Standard fugitive PM control measure – asphalt manufacture	100%	100%	10	N/A	N/A	N/A	N/A	79	85
Standard fugitive PM control measure – Part B processes	100%	100%	10	N/A	N/A	N/A	N/A	552	611
Standard fugitive PM control measure – coke production	100%	100%	10	N/A	N/A	N/A	N/A	30	30
Standard fugitive PM control measure – construction	100%	100%	10	N/A	N/A	N/A	N/A	86	91
Standard fugitive PM control measure – cement and concrete batching	100%	100%	10	N/A	N/A	N/A	N/A	19	18

Note 1: The costs presented here are the average costs for each abatement measure (in case a measure was given a range of costs). Where a cost per tonne of pollutant abated was applied in the analysis, no capital and operating costs are presented (i.e. N/A). A discount rate of 3.5% is considered in the analysis.

Note 2: These figures are *in addition to* BAU level: in other words this equates to BBAU uptake level – BAU uptake level.

Table A14.3 Summary of beyond BAU abatement measures efficiency for the combined PM measure

Abatement measure	Emission reduction efficiency (%)						Reduction in 2025 emissions (kt)						Reduction in 2030 emissions (kt)					
	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3
Standard fugitive PM control measure – Quarrying									0.61	0.18					0.66	0.19		
Standard fugitive PM control measure – brick manufacture (non-Fletton)									0.10	0.06					0.10	0.06		
Standard fugitive PM control measure – integrated steel works, stockpiles									0.21	0.06					0.21	0.06		
Standard fugitive PM control measure – asphalt manufacture									0.04	0.02					0.04	0.02		
Standard fugitive PM control measure – Part B processes									0.25	0.13					0.28	0.14		
Standard fugitive PM control measure – coke production									0.03	0.01					0.03	0.01		
Standard fugitive PM control measure – construction									0.06	0.02					0.07	0.02		
Standard fugitive PM control measure – cement and concrete batching			9.5%	9.5%					0.01	0.00					0.01	0.00		

A14.4 References

1. AEA (2012). UK Informative Inventory Report (1980 to 2010)
2. Entec (2004) “Revision of Cost Curves for PM_{10}”
3. Entec (2006) “Development of $PM_{2.5}$ Cost Curves” (Draft Final Report)
4. Entec (2011). Multi Pollutant Measures Database

A15. Contents

A15. Aviation

A15.1 Sector profile

Aviation is a major UK industry, carrying over 235 million passengers a year and over 2.3 million tonnes of freight (4), and there are currently 56 large scale commercial airports in the UK (5).

The National Atmospheric Emissions Inventory (NAEI) emission projections for aviation, based on DECC's UEP43 forecasts and the 2009 baseline, indicates that the key source of NOx emissions is domestic flights, within their take-off and landing cycle (TLO), therefore this analysis for the aviation sector has focused on this emission source[1]. The NAEI data suggests that in 2010 the sector contributed 0.24% of total UK NOx emissions. Whilst the emission projections suggest that aviation contributes to SO_2, VOC and PM emissions, this is not considered significant (<0.004% of total emissions), therefore measures for SO_2, VOC and PM control from these sources have not been investigated.

A15.2 Business as usual policies and abatement measures

During the last 3 years, the expectation that tighter standards for NOx emissions in the LTO phase will be introduced by the International Civil Aviation Authority (ICAO) has been the main driver for improvements in NOx emissions. In response to this expectation there have been significant improvements in aircraft engines with lower emissions of NOx per unit of thrust at constant pressure ratios. In spite of this trend towards more stringent emissions standards, there has been little progress in reducing NOx emissions per seat kilometre because aircraft have become more fuel efficient with the resulting increase in engine pressure ratios permitted under the ICAO standards. These standards allow engines with higher pressure ratios to emit more NOx per unit of thrust. As a result, NOx emissions per seat kilometre have remained relatively constant over time. (1)

For the future, the inclusion of aviation in the ETS and the implementation of air traffic management improvements, such as Single European Skies, will have the effect of reducing NOx emissions as well as CO_2 relative to baseline trends. There has been progress in incorporating Advisory Council for Aviation Research and Innovation in Europe (ACARE) targets for in the aircraft fleet. These targets introduced by ACARE include reductions per passenger kilometre of 50% CO_2, 80% NOx and a 50% reduction in noise. This will lead to further improvements, in emissions though this will be limited prior to 2020 (7). The key driver in the period up to 2050 will be the rate of uptake of ACARE targets. Even under conservative assumptions on uptake, NOx emissions are likely to grow significantly more slowly than air traffic (1).

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[1] Although reported in the NAEI, emissions from domestic and international cruising and military aircraft are not included under the National Emission Ceilings Directive (NECD) and therefore these sources are not considered in this assessment.

A15.3 Beyond business as usual potential abatement measures

15.3.1 Early aircraft retirement

There is the potential for early retirement of older, less efficient aircraft in airline fleets as an abatement strategy under a BBAU scenario. This would mean airlines actively replacing older aircraft models with newer, more efficient models on average within a 20 year period, which is a shorter period than that of current practices which is a 30 year period (8).

New aircraft typically have 10-40% lower emissions than an equivalent size aircraft that is over 20 years old (9)(10)(11). The cost of a new commercial passenger jet aircraft is £ 7 - 8 million (1). Based on British Air Transport Association figures there are approximately 988 aircraft in the UK fleet, and data from Boeing showed an average annual retirement rate of 4.5%, therefore early retirement after 20 years would result in 44 aircraft per year being replaced.(3)(6)

15.3.2 Optimised LTO practices / Derated take-off

The optimisation of Landing and Take-Off cycle practices (LTO) is another potential, non-technical abatement strategy under a BBAU scenario. Aircraft can use reduced engine thrust during take-off and landing along with other efficiency actions while taxing to achieve a reduction in NOx emissions of 14.5%. This study suggests that such operational changes could be implemented by all aircraft. A study by Partnership for Air Transportation Noise and Emissions Reduction (PARTNER) showed that for this abatement measure, as well as achieving a reduction in NOx, there is a reduction in fuel consumption of 12.3%, with an associated saving in CO_2 emissions and fuel costs. (2)

A15.4 Summary of measures and costs

Table 16.1 summarises the estimated cost of each abatement measure for the UK aviation sector based on the UK domestic fleet. The costs in the summary table are based on the average cost of each abatement technology. Table 16.2 presents the reduction efficiency of the abatement measures and the associated reduction in emissions.

Table 15.1 Summary of beyond BAU abatement measures for the Aviation sector for 2025 and 2030 [1]

Abatement measure	Future uptake of measure (%)		Operating life (years)	Capital Costs (£k, 2011 prices)		Annual operating costs (£k, 2011 prices)		Total annualised costs (£kpa, 2011 prices)	
	2025	2030		2025	2030	2025	2030	2025	2030
Optimised LTO practice /derated take-off	100	100	20					-11,224	-12,365
Early Aircraft retirement	33	8	20					3,919,396	1,296,219

Note 1: Capital and annual costs data was not available for this sector, only total annualised cost data.

Note 2: Aircraft retirement is based on an estimated UK air fleet size based on data from BATA and Boeing (3) (6)

Note 3: Total annualised costs based on marginal abatement costs from OMEGA (1)

Table 15.2 Summary of beyond BAU abatement measures efficiency for the aviation sector

Abatement measure	Emission Reduction Efficiency (%),	Emission reductions of NOx 2025 (kton)	Emission reductions of NOx 2030 (kton)
Optimise LTO practice* / Derated take-off	14.5%	0.30	0.33
Early Aircraft retirement	25.0%	0.41	0.13

Note 1: Optimise LTO practice / derated take-off Emissions reduction efficiency based on figure from Partner report (2)

A15.5 References

1. J. Morris et al (2009) Omega: A framework for Estimating the Marginal Costs of Environmental Abatement for the Aviation Sector http://open.academia.edu/alexrowbotham/Papers/1126337/A_Framework_for_Estimating_the_Marginal_Costs_of_Environmental_Abatement_for_the_Aviation_Sector#outer_page_41 Last updated 2012 [Accessed July 2012]

2. D. King (2005) Assessment of the effects of operational procedures and derated thrust on American Airlines B777 emissions from London's Heathrow and Gatwick airports http://web.mit.edu/aeroastro/partner/reports/drate-rpt.pdf Last updated 2012 [Accessed July 2012]

3. British Air Transport Association (2012) Welcome to the British Air Transport Association http://www.bata.uk.com/ Last updated 2012 [Accessed July 2012]

4. Civil Aviation Authority (2011) UK Airport Statistics: 2011 – annual http://www.caa.co.uk/default.aspx?catid=80&pagetype=88&sglid=3&fld=2011Annual Last updated 2011 [Accessed July 2012]

5. Department for Transport (2012) http://www.dft.gov.uk/aviation Last updated 2012 [Accessed July 2012]

6. Boeing (2012) Long Term Market Outlook 2012-2031 http://www.boeing.com/commercial/cmo/ Last updated 2012 [Accessed July 2012]

7. M. Milner (2009) Aviation Industry looks to cut emissions http://www.guardian.co.uk/environment/2009/jan/16/plane-emissions-heathrow-third-runway Last updated 2009 [Accessed July 2012]

8. P.Morrell & L.Dray (2009) Omega, Environmental aspects of fleet turnover, retirement and life cycle final report, http://www.omega.mmu.ac.uk/Events/Cranfield%20Cambridge%20Omega%20T2-06%20draft%20FINAL4%20030409.pdf, Last updated 2009 [Accessed July 2012]

9. Holsclaw (2010) FAA Perspective on ICAO's Progress on NOx Emissions. Available from: http://www.epa.gov/air/caaac/mstrs/may2010/7_Holsclaw.pdf

10. Rolls Royce (2007) NOx reduction http://www.rolls-royce.com/reports/environment_report_07/reducing-en-impact/nox-reduction.html [Accessed August 2012]

11. London Assembly (2012) Plane Speaking http://www.london.gov.uk/publication/tackling-air-and-noise-pollution-around-heathrow

A16. Contents

A16.Shipping

A16.1 Sector profile

Emissions to air from ships are primarily due to the combustion of fuels for propulsion and onboard power supply. They are a source of sulphur dioxide, nitrogen oxides, particulate matter (PM) and carbon.

The sources to be investigated, along with their respective contributions to emission totals in 2030 are shown in Table A16.1. Emissions from these sources are projected to remain constant between 2010, 2025 and 2030.

Table A16.1 Sources to be investigated for shipping

Source (NFR – Sector – activity)	Contribution to total UK emissions in 2030
PM_{10}	
6Cd_Shipping - coastal_Gas oil	1%
z_1A3ai(ii)_Shipping - coastal_Fuel oil	1%
$PM_{2.5}$	
1A2fi_Shipping - coastal_Gas oil	1%
1A1c_Shipping - coastal_Fuel oil	1%
NO_X	
1A1c_Shipping - coastal_Gas oil	5%
1A4bi_Shipping - coastal_Fuel oil	1%
SO_2	
0_Shipping - coastal_Gas oil	3%
0_Shipping - coastal_Fuel oil	1%

Although 1A4ai_Shipping - naval_Gas oil is forecast to contribute 1% of national $PM_{2.5}$ emissions, 3% of SO2 emissions and 4% of NOx emissions in 2030, it is not included within the scope of this work due to difficulty in regulating the source.

A16.2 Business as usual policies and abatement measures

Currently, the main policy drivers for reducing air pollutant emissions from shipping are the International Maritime Organization (IMO) Regulations for the Prevention of Air Pollution from Ships, adopted in the 1997 Protocol to MARPOL 73/78 and included in Annex VI of the Convention, which entered into force in May 2005. MARPOL Annex VI sets limits on SOx and NOx emissions from ship exhausts. It includes a global cap of 4.5% m/m on the sulphur content of fuel oil and also set provisions allowing for special Sulphur Emission Control Areas (SECAs) where either the sulphur content of fuel oil used on board ships must not exceed 1.5% m/m, or ships must fit technologies to achieve equivalent SOx emissions. Limits on emissions of NOx from diesel engines were also set, known as Tier I, II and III standards. The Baltic Sea is designated as a SECA in the protocol and the North Sea was adopted as a SECA in July 2005 (the North Sea SECA entered into force on 21st November 2006, to be fully implemented 12 months later, on 22nd November 2007).

A revised Annex VI entered into force in 2010 which allows for an Emission Control Area to be designated to limit emissions from ships of SO_x and particulate matter, or NOx, or all three pollutant species, subject to a proposal from a Party or Parties to the Annex which would be considered for adoption by the Organization, if supported by a demonstrated need to prevent, reduce and control one or all three of those emissions from ships. The 2008 Annex VI revision also stipulated time-limited sulphur content limits, with the aim to reduce emissions of SOx and particulate matter.

Business as usual measures included in the projections include a forecast 10% uptake of sea water scrubbers by 2020, in order to meet MARPOL sulphur limits as an alternative to the use of lower sulphur fuel. Slide valves, which optimise the distribution of the fuel spray in the combustion chamber, resulting in improved fuel air mixing prior to combustion, are assumed to be standard in all 2-stroke slow speed engines since 2000.

A16.3 Beyond business as usual potential abatement measures

The main body of measures are based upon AMEC’s 2009 Review of ship emissions abatement techniques for Defra, and supported by data from the Ship Emissions Inventory (AMEC, 2010). The impacts of the potential abatement measures considered is shown in Table A16.2.

Table A16.2 Summary of technical measures reviewed and estimates of their associated impact on emissions

Measure	NOx	SOx	PM	VOC	CO_2	Fuel
Engine modifications						
Direct Water Injection (DWI)	▼ (30 – 60%)		▼ (20%)	▲/▼	▲/▼	▲/▼ (5%)
Humid Air Motors (HAM)	▼ (45-85%)				▼	▼
End of pipe technologies						
Waste heat recovery	▼ (10-12%)	▼ (10-12%)	▼ (10-12%)	0	▼ (10-12%)	▼ (10-12%)
Selective Catalytic Reduction (SCR)	▼ (80-95%)	0	0	0	▲ (1-3%)	0
Particulate filters	0	0	▼ (99%)	0	▲ (1-3%)	▲ (1-3%)
Sea Water Scrubbing (SWS)	▼ (0-7%)	▼ (75-100%)	▼ (25-95%)		▲ (2%)	▲ (2%)

Measure	**NOx**	**SOx**	**PM**	**VOC**	**CO_2**	**Fuel**
Fuel measures						
LNG	▼ (80-90%)	▼ (99%)	▼	▲/▼	▼ (25%)	▼
Water-diesel emulsion	▼ (10-50%)	▼	▼ (15-90%)			▼
*Biofuels 100% biodiesel or plant oil**	▲ *(1-18%)*	▼ *(95-99%)*	▼ *(50 -82%)*	▼ *(67%)*	▼ *(78-80%)*	▲ *(3%)*
Other						
Kites	▼	▼ (15%)	▼	0	▼ (15%)	▼ (15%)

Key:

▼: decrease, ▲: increase, ▲/▼: different tests show increase or decrease, 0: no change

* Measure impacts have since been reviewed and amended in the current update of the model.

Source: AMEC 2009

Additional measures reviewed but not included on a basis of cost effectiveness of lack of data include Turbochargers, Exhaust Gas Recirculation (EGR), Combined NOx and PM abatement, Fuel additives and Oxygenated Fuels.

16.3.1 NOx

The main group of measures with good potential NOx abatement are engine modifications, including Direct Water Injection (DWI), Humid Air Motors and Exhaust Gas Recirculation. SCR is also technically feasible as an end of pipe measure.

Direct Water Injection

Engines with DWI are equipped with a combined injection valve and nozzle that allows injection of water and fuel oil into the cylinder. Water injection takes place before fuel injection or in parallel with the fuel, resulting a cooler combustion space and therefore lower NOx emission. Technically, DWI can be applied to all marine diesel engines, although space limitations for fresh water tanks will prevent 100% uptake. Uptake is therefore modelled as 95% of post-2000 engines, assuming a 3.5% ship replacement rate, which is equivalent to 70% of the whole fleet in 2020, 88% of the whole fleet in 2025, and maximum uptake potential by 2030. Entec (2005) differentiates costs between small, medium and large vessels. The average value, weighted by the proportion of total installed engine capacity, is €0.6/MWh for capital cost and €2.1/MWh for operating and maintenance costs, and has been used in IIASA (2007). This is consistent with the lower end of the €350 – 410/tonne NOx range quoted by the Finnish Environment Institute (2006).

Humid Air Motors

Humid Air Motors is an alternative means of lowering the combustion temperature and thereby reducing NOx formation. Distilled water is used to humidify the intake air, with a moisture to fuel ratio of 3:1. Technically, HAM can be applied to all marine diesel engines, and therefore the BBAU uptake could possibly be ~99%. This measure can be retrofitted or installed on new engines, which represents possible BBAU uptake of 59% and 43% of the fleet respectively in 2025, and 38% and 61% in 2030. Entec (2005) differentiates costs between small, medium and large vessels. The average value, weighted by the proportion of total installed engine capacity, is €2.8/MWh for capital cost and €0.2/MWh for operating and maintenance costs, for retrofit, and €2.2/MWh for capital cost and €0.2/MWh for operating and maintenance costs, for retrofit, which have been used in IIASA (2007). This is consistent with the €200 – 310/tonne NOx range quoted by the Finnish Environment Institute (2006).

SCR

AEA (2008) describes SCR as ‘based on a catalysed reaction between urea and NOx that occurs in the flue gas, in which NOx is reduced to nitrogen. Urea solution is injected into the post-combustion hot flue gas and the catalyst (titanium or vanadium oxide) is housed in the exhaust channel. The process is considered an ‘add-on’ and can therefore be used in conjunction with any engine, however, the temperature of the exhaust gases must be above around 270°C for the process to function properly.’ SCR is presently the most common method to reduce NOx emission from ships and is estimated to be commercially installed on more than 300 engines world-wide, and has been in commercial use since 1989 (Lövblad & Fridell, 2006). Entec (2005) estimates that business as usual (BAU) take-up of SCR in 2020 will be approximately 1% of existing and new vessels, and that the maximum beyond business as usual (BBAU) take-up could be 99% of the fleet in 2020. This is distributed between three size categories with 52% being small (<7500kW) vessels, 38% medium and 10% large (>20125kW). No major changes in uptake potential are forecast to 2025 and 2030 for either BAU or BBAU. Costs are based on AMEC (2009). Because SCR is very capital intensive, the estimation of its cost is most sensitive to the size of the installation, the assumed life of the retrofit, and the discount rate used to calculate net present value (FoEI, 2005). Capital costs vary by vessel size and whether it is a retrofit or new build, operating costs also vary by vessel size.

16.3.2 PM

The two main measures considered under PM abatement are Diesel Particulate filters (DPF) and Water Diesel Emulsion.

Diesel particulate filters

Diesel Particulate filters can be used to significantly reduce emissions of particulates from diesel engines. Such a filter utilises a porous substrate, commonly in a honeycomb formation, with catalytically coated silicon carbide (SiC) particulate matter filters to physically trap soot particles. During operation particles build up on the filter, necessitating regeneration of the filter to oxidise the particles. This regeneration requires a catalyst to lower the reaction temperature sufficiently to promote oxidation at more typical marine diesel engine exhaust gas temperatures. Very high PM removal efficiencies (>99%) are possible if low sulphur fuel is used (<0.5% S); higher sulphur content poisons the catalyst. A projected maximum uptake of 90% in 2025 and 2030 is therefore based on the assumed portion of the fleet using low sulphur fuels to meet MARPOL regulations, as opposed to scrubbers. Costs are based on three case studies of DPFs fitted to Heavy Goods Vehicles in order to meet the London Low Emission Zone requirements (TfL, 2012) giving a derived average capex of £24/kW. A high bound cost estimate is derived by using a linear projection to scale costs to three illustrative average sized vessels for UK coastal shipping based on the 2009 Defra Ship Emissions Inventory (Amec, 2010). A low bound capex cost is derived by using a log scale regression, which simulates a common £/kW trendline. Operating costs are assumed to be 5% of capital costs, based on the HGV data.

Combined NOx and PM abatement systems exist for marine applications. Such systems incorporate both an SCR reactor for NOx abatement with either a particulate filter or a diesel oxidation catalyst or both for PM abatement. However although suppliers were contacted, it was not possible to obtain costs for this measure.

Water in fuel emulsion

Water in fuel emulsion or “FWE” consists of emulsions of water in diesel fuel, typically made of 10 to 30% water mixed with fuel, with certain tests going to 50%[1]. For best performance, water droplets in the emulsion should be as small as possible, and either a mechanical or ultrasonic homogeniser can be used. Due to the fact that, in shipping, fresh water needed for FWE has to be produced onboard, the water amount for the emulsion for medium - speed diesel engines has been limited to a maximum of 20 %.[2] Water in fuel emulsion technology is proven to significantly reduce NOx and PM emissions simultaneously. The lower temperature and greater combustion from the water in fuel emulsification have the following results including a reduction in nitrogen oxides (NOx) in a one-to-one relationship with the emulsion's water content, (25% water content = 25% NOx reduction), a reduction of PAH-generated particulate matter equal to 2 to 3 times the emulsion's water content (25% water yields 50% to 75% reduction of PAH-generated particulate matter), up to a 5% reduction in carbon dioxide and possible reduction in sulphur emissions. The technology is suitable for engines greater than 9,000 kW, equivalent to 27% of the fleet. The cost for equipment and installation of on-board fuel-water emulsion systems can be approximately £170k or less for oceangoing marine vessels in 2008. The fact that this technology requires large intermediate and storage tanks for fresh water or the choice of having a desalination unit on-board which can provide fresh water can increase the capital cost even more. Installation costs (and opportunity costs) are also unknown. Therefore the annual operating cost for maintenance can range from £0 to £29k for oceangoing marine vessels in 2008. Broadly speaking, when an engine requires replacement or modification, in order for a FEW system to be applied, the cost can be extremely high and it can be only effective when supported by a state subsidy program. It should be noted that the costs presented for this measure are based on a draft document published by the Air Resources Board on 30th October 2002 – it has not been possible to obtain updated costs from California ARB.

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[1] Man B&W, ‘Exhaust Gas Emission Control Today and Tomorrow: Application on Man B&W Two-stroke Marine Diesel Engines’. http://www.manbw.com/files/news/filesof9187/5510-0060-00ppr.pdf

[2] http://www.mandiesel.com/files/news/filesof935/0801Emissions.pdf

16.3.3 SOx

A key technology for SOx abatement is scrubbers, whereby the exhaust gases containing SOx are passed through a chamber where they come into contact with chemicals (wet or dry) which react with the SOx and remove it from the exhaust gases. The most common type of scrubbing for marine applications is Sea Water Scrubbing (SWS), where the SOx and Calcium Carbonate ($CaCO_3$) in the seawater react to form Calcium Sulphate (gypsum) and CO_2. Particulate matter is also removed from the exhaust gases. Given the large uncertainties over the economic and market factors it is difficult to project the uptake of this technology; therefore it is unsurprising that there is a range of predictions of uptake in the available literature.

Considering the impact of the revised Annex VI, the IMO[3] considers that 10% of the annual fuel consumed at sea will be scrubbed by 2020, while some suppliers of scrubbers are more optimistic and predict that up to 30% of vessels will have fitted scrubbers by 2020[4] due to a shortage of low sulphur fuels. Costs are based on workings in the Defra Ship Emissions Inventory 2009 (AMEC, 2010). New and retrofit costs were calculated for vessels with 2, 6, 10, 14 and 20MW main engines for a number of sources (literature and suppliers) and the results averaged to produce average costs (£/kW) in Table A16.3.

Table A16.3 Average Costs of Scrubbing Equipment

	Cost Main Engines Only (£/kW)	Cost Main and Auxiliary Engines (£/kW)
New:	122	199
Retrofit:	156	203

All costs are in GBP (March 2009).

16.3.4 CO_2 and fuel saving measures

A number of measures are considered primarily on a basis of CO_2 abatement and/or as a fuel saving measure. These often impact across a range of air pollutants. Measures considered in this category include waste heat recovery, fuel switching to LNG, biofuel (100% plant or biodiesel) and kites.

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[3] IMO report: Sub-committee on Bulk liquids and gases. Revision of MARPOL ANNEX VI and the NOx Technical Code – Input from the four subgroups and individual experts to the final report of the Informal Cross Government/Industry Specific Group of Experts (shipping subgroup). (December 2007)

[4] ‘Krystallon – An Overview’ doc.

Waste heat recovery

In Waste Heat Recovery, exhaust gas energy is used to drive a gas turbine or generate steam to drive a turbine. A consortium of system component suppliers, led by Siemens has developed an integrated waste heat recovery system (SISHIP Boost) for container vessels[5]. Wartsila have incorporated technology from Siemens and existing Sulzer engines to produce a system that utilises both an exhaust gas driven turbogenerator and a steam turbine to recover 11% of engine power (68.6mW engine). Simplified waste heat recovery systems are available for vessels which only require the recovered energy to be sufficient to cover all onboard electricity demand while at sea (e.g. Wartsila RT-flex82C)[6]. The A.P. Moller-Maersk group currently operates a fleet of six, 7,500 TEU and a number of 11,000 TEU container ships fitted with combined steam turbine and turbo generator system that delivers power as shaft motor and as on-board electricity. This indicates that WHR is already in use and there will therefore be some BAU uptake. Space restrictions may limit the retrofit of WHR in some instances. For this assessment it is estimated that there will be 80% BBAU uptake. The costs for this have been based upon the illustrative example of a Wartsila[7] system suitable for use on a 'mega' 11,000 TEU ship, with capex of £4.85m and opex of £-1.15m/year, based on an assumed 85% engine load and bunker fuel price of US$250/t.

LNG

Fuel switching to LNG entails liquefying natural gas, which is then stored in cryogenic tanks (at around -162°C); it is re-vaporised when supplied to the engine. There is thus an additional space requirement from the tanks on ships and an energy requirement on shore to liquefy and transport the fuel. The use of a different fuel stipulates the need for either additional infrastructure to supply LNG to bunkers or to use regional routes where LNG is already available. It is difficult to predict the likely BAU take-up of LNG-powered ships due to a number of barriers to implementation and the volatility of the oil/gas price differential. The study assumes 100% uptake in post 2014 ships as technically feasible, which is equivalent to 44% of the fleet in 2025 and 61% of the fleet in 2020.

Currently, bulk LNG costs are about the same as that of residual fuel oil, and significantly cheaper than distillate fuels, therefore there is a considerable economic incentive for a move towards LNG (AEA, 2008). The 'new technology' additional costs – related to the learning process of operating a certain type of technology – are expected to be moderate for LNG-fired ships partly because such ships already exist and partly because the technology-shift is smaller than that required for e.g. hydrogen or nuclear ships (AEA, 2008). The first LNG ferry which was a prototype, the 'Glutra' in Norway, cost some 30% more than an equivalent diesel-electric ferry. Natural gas ferries will have to be somewhat more expensive than their diesel counterparts, but this extra cost will,

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[5] http://www.industry.siemens.com/broschueren/pdf/marine/siship/en/SISHIP%20Boost_WHRS.pdf

[6] Wartsila, 2007, Waste Heat Recovery, http://www.wartsila.com/Wartsila/global/docs/en/ship_power/media_publications/brochures/product/waste-heat-recovery-wartsila.pdf

[7] http://www.wartsila.com/Wartsila/global/docs/en/ship_power/media_publications/brochures/product/waste-heat-recovery-wartsila.pdf

according to the opinion of MRF, be reduced down to some 10% through further LNG ferry projects (Stokholm & Roaldsøy, 2002).

Einang (2007): Costs for RoRo Freight vessel

- Normal diesel operation €25m
- Additional cost for PMG propulsion ~€2m (8%)

Fuel Costs for an LNG ferry (17 knots): MDO 196million; LNG (est.) 24 million

LNG Chain, costs can be ascribed to:

- Pipeline feed gas price (50-60%)
- Liquefaction (20-25%)
- Distribution (20-25%)

If crude price is 30$/bbl, LNG estimated to be 10-15% lower than MDO

If crude price is 60$/bbl, LNG estimated to be 20-30% lower than MDO

Biodiesel

Biodiesel is a non-toxic, biodegradable, and renewable fuel that can be used in diesel engines with little or no modification. It is made up of chain alkyl (methyl or ethyl) esters and can be produced from a variety of vegetable oils such as soybean or rapeseed oils, animal fats, waste vegetable oils, or microalgae oils. However, the limited availability of feedstock and the controversy on how much they can contribute to reduce greenhouse gas emissions means that the beyond BAU potential uptake is hard to predict. The introduction of the second generation biofuels, such as synthetic diesel fuel (synfuel), will likely bring tougher regulations for promoting the use of biofuels not only for road transport but also for ships. If tougher regulations are imposed then uptake targets such as those under the Road Transport Fuel Objective (RTFO) will likely be increased, so the BBAU content could possibly be 20% by 2020. No change in uptake is assumed to 2030 due to high levels of uncertainty. In European Commission (2007)[8] a range of additional costs (compared to fossil fuels) are presented for UK biofuels in relation to the Renewable Transport Fuel Obligation (RTFO). The real production price differential of biodiesel, including extra production costs, is £0.21 per litre. The range of the additional production costs shows that the extra costs for biodiesel could vary between £-0.04 and £0.30 per litre. No impact on carbon emissions has been assumed due to considerable uncertainty in ILUC impacts, see for instance Schroten, A. et al (2011).

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[8] http://ec.europa.eu/community_law/state_aids/comp-2006/n418-06.pdf

Towing kites

Wind power can be utilised in various ways on ships. One of the most promising wind technologies, considered here, is the use of towing kites. With kites there is no need for masts which obstruct loading cranes, the technology can be retrofitted, and it can be built, repaired and maintained remotely. From the SkySails example vessel applications, the largest of vessel types are not well represented (SkySails, 2008). Therefore vessels from the UK inventory only <25,000GT have been included for the comparison. The vessel types that have been included for potential application of kites are Bulk Carriers, Container Ships, Fishing, General Cargo, Ro-Ro Cargo and Tankers. These comprise around 7,900 vessels, or 55% of the 2007 fleet. Fuel consumption (and therefore CO_2) savings are estimated by SkySails to be between 10% and 35%, depending on the wind conditions. AEA (2008) provide an opinion that this fuel saving may be more of the order of 5% (for tankers and bulk carriers) to 10% (cargo ships), but that higher savings would be realised at slower speeds. For the purposes of this report, taking into account weather patterns and routes for which a kite cannot be used optimally, a fuel consumption saving of 15% is assumed. The capital costs include both the acquisition and initial installation costs on the ship, assumed to be £175 per kW installed main engine power (derived from SkySails, 2008). The operating costs comprise two components: the annual servicing and maintenance costs – assumed to be £18/kW (derived from SkySails, 2008) – and the annual fuel cost saving. Annual fuel savings are estimated based on the assumption that in 2020, 60% of the fleet will use RO, and 40% MDO. Fuel prices assumed were MDO £460/kW, and RO £260/kW (derived from SkySails, 2008).

A16.4 Summary of measures and costs

Table A16.4 summarises the estimated cost of each abatement technology for the shipping sector. The costs in the summary table are based on the average cost of each abatement technology. The range of costs were summarised in Section 1.3 for NOx, SO_2 and dust abatement measures respectively. Cost are presented in terms of annualised costs, which have been derived in terms of cost reduction of the primary pollutant, so that for example DWI and HAM are costed on total NOx abatement potential, and fuel switch to LNG is costed on sulphur. Table A16.5 presents the reduction efficiency of the abatement measures and the associated reduction in emissions.

Table A16.4 Summary of beyond BAU abatement measures for the shipping sector for 2025 and 2030[1]

Abatement measure	Future uptake of measure (%)		Operating life (years)	Capital Costs (£k, 2011 prices)		Annual operating costs (£k, 2011 prices)		Total annualised costs (£kpa, 2011 prices)	
	2025	2030		2025	2030	2025	2030	2025	2030
Waste Heat Recovery	80%	80%	25	-	-	-	-	-389,580	-389,580
Kites	56%	56%	8	-	-	-	-	-56,805	-56,805
Fuel switch to LNG	44%	62%	25	-	-	-	-	-2,008	-3,114
100% Biodiesel or Plant Oil	20%	20%	25	-	-	-	-	145,295	145,295
Charge air humidification (humid air motors, HAM) new	43%	61%	25	-	-	-	-	2,289	3,242
Charge air humidification (humid air motors, HAM) retrofit	56%	38%	25	-	-	-	-	2,381	1,613
Direct Water Injection (DWI)	84%	95%	25	-	-	-	-	4,008	4,549
Water diesel emulsion	27%	27%	25	-	-	-	-	32,903	32,903
Selective Catalytic Recovery (SCR_small)	52%	52%	14	-	-	-	-	167,439	167,439
DPF	90%	90%	8	-	-	-	-	347,603	347,603

Note 1: The costs presented here are the average costs for each abatement measure (in case a measure was given a range of costs. A discount rate of 3.5% is considered in the analysis.

Note 2: No capital and operating costs are presented because a cost/ton of pollutant abated was applied in the analysis.

Table A16.5 Summary of beyond BAU abatement measures efficiency for the shipping sector

Abatement measure	Emission reduction efficiency (%)						Reduction in 2025 emissions (kt)						Reduction in 2030 emissions (kt)					
	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3
Waste Heat Recovery	11.0%	11.0%	11.0%	11.0%	0.0%	0.0%	2.44	0.83	0.11	0.10	0.00	0.00	2.44	0.83	0.11	0.10	0.00	0.00
Kites	0.0%	15.0%	0.0%	0.0%	0.0%	0.0%	0.00	0.79	0.00	0.00	0.00	0.00	0.00	0.79	0.00	0.00	0.00	0.00
Fuel switch to LNG	85.0%	99.0%	0.0%	0.0%	0.0%	0.0%	7.74	3.14	0.00	0.00	0.00	0.00	11.88	4.87	0.00	0.00	0.00	0.00
100% Biodiesel or Plant Oil	0.0%	99.0%	38.0%	38.0%	0.0%	0.0%	0.00	1.87	0.09	0.09	0.00	0.00	0.00	1.87	0.09	0.09	0.00	0.00
Charge air humidification (humid air motors, HAM) new	65.0%	0.0%	0.0%	0.0%	0.0%	0.0%	7.79	0.00	0.00	0.00	0.00	0.00	11.03	0.00	0.00	0.00	0.00	0.00
Charge air humidification (humid air motors, HAM) retrofit	65.0%	0.0%	0.0%	0.0%	0.0%	0.0%	10.06	0.00	0.00	0.00	0.00	0.00	6.81	0.00	0.00	0.00	0.00	0.00
Direct Water Injection (DWI)	45.0%	0.0%	20.0%	20.0%	0.0%	0.0%	10.44	0.00	0.21	0.19	0.00	0.00	11.85	0.00	0.23	0.22	0.00	0.00
Water diesel emulsion	30.0%	0.0%	53.0%	53.0%	0.0%	0.0%	2.25	0.00	0.18	0.17	0.00	0.00	2.25	0.00	0.18	0.17	0.00	0.00
Selective Catalytic Recovery (SCR_small)	80.0%	0.0%	0.0%	0.0%	0.0%	0.0%	11.64	0.00	0.00	0.00	0.00	0.00	11.64	0.00	0.00	0.00	0.00	0.00
DPF	0.0%	0.0%	99.0%	99.0%	0.0%	0.0%	0.00	0.00	1.09	1.04	0.00	0.00	0.00	0.00	1.09	1.04	0.00	0.00

A16.5 References

1. AMEC (2009): Ship Emissions Abatement Measures Review. Final report for Defra..

2. AMEC (2010): UK ship emissions inventory. Final report for Defra.

3. AEA (2008) Greenhouse gas emissions from shipping: trends, projections and abatement potential. Final report for the Committee on Climate Change. Report by AEA Energy & Environment, Entec, Manchester Metropolitan University, Marintek, DLR and CE Delft.

4. Einang, P.M. (2007) LNG som drivstoff for skip. Presentation given at Gasdagarna 2007, Båstad, Sweden, 17-18th October 2007.

5. Entec (2005) Service Contract on Ship Emissions Assignment, Abatement and Market-based Instruments Task 2b NOx abatement. Report for the European Commission.

6. Finnish Environment Institute (2006) Ship emissions and technical emission reduction potential in the Northern Baltic Sea.

7. FoEI (2005) *Reducing Shipping Emissions of Air Pollution — Feasible and Cost-effective Options*. Friends of the Earth International. Submission to the IMO Marine Environment Protection Committee, 53rd session.

8. IIASA (2007) *Analysis of Policy Measures to Reduce Ship Emissions in the Context of the Revision of the National Emissions Ceilings Directive*.

9. Lövblad, G. & Fridell, E. (2006) Experiences from use of some techniques to reduce emissions from ships. Report produced for the Swedish Maritime Administration and Region Västra Götaland by Profu and the Swedish Environmental Research Institute.

10. Schroten, A., Essen, H, Smokers, Warringa, G., Bolech, M. and Fraga, F. (2011) *Cost effectiveness of policies and options for decarbonising transport.* Task 8 paper produced as part of a contract between European Commission Directorate-General Climate Action and AEA Technology plc; see website www.eutransportghg2050.eu

11. SkySails (2008) SkySails webpage 'A Win-Win for owners, operators and charterers. SkySails Business Cases'. Available at: http://www.skysails.info/english/products/skysails-for-cargo-ships/business-cases/

12. Stokholm, R.M. & Roaldsøy, J.S. (2002) LNG used to Power the Ferry "Glutra" in Norway – The World First Ferry To Run On LNG. Available from http://www.ipt.ntnu.no/~jsg/undervisning/naturgass/dokumenter/Stokholm2002Paper.pdf

13. TfL (2012), 'Low Emissions Zone, What are my options?' DPF Case Studies. Available from http://www.tfl.gov.uk/roadusers/lez/17701.aspx

A17. Contents

A17.Rail

A17.1 Sector profile

The NAEI emission projections for rail, based on DECC's UEP43 forecasts and the 2009 baseline, indicates that the two main sources of emissions are gas oil combusted in passenger intercity and regional rail transport.

The sources to be investigated, along with their respective contributions to emission totals are shown in Table A17.1. Emissions from these sources are projected to remain constant between 2025 and 2030. There is a projected 11% drop in activity levels between 2020 and 2030 (AEA, 2012) which is therefore assumed to occur between 2020 and 2025 based on total projected emissions.

Table A17.1 Sources to be investigated for rail

Source (NFR – Sector – activity)	Contribution to total UK emissions in 2030
NO_x	
Railways - regional_Gas oil	2%
Railways - intercity_Gas oil	2%
$PM_{2.5}$	
Railways - regional_Gas oil	0.34%
Railways - intercity_Gas oil	0.41%

A17.2 Business as usual policies and abatement measures

At a European level, key policies include Directive 2002/88/EC[1], relating to measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery, which implements two stages of emission limit values for compression ignition engines. In addition emission limits are introduced for commercial inland shipping and rail engines and locomotives. The two stages of emissions limits for new diesel engines set the maximum allowable emissions of NOx, PM, hydrocarbons and carbon monoxide. The higher Stage II has now entered into force for all engines. Directive 2004/26/EC amending Directives 97/68/EC and Directive 2002/88/EC, implements 3 further stages of future emissions limits (Stage IIIA, IIIB & IV) that apply to equipment already within the scope of Directive 97/68/EC. All engines installed that are not already available in the market will have to comply with the emission limits before 2015 (with the exception of Stage IV for engines other than constant speed engines with a production date prior to 31 December 2013 and 30

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

September 2014 where the compliance date may be postponed by two years). **Stage IV does not apply to engines for the propulsion of locomotives or railcars.**

Table A17.2 Emission limits in Directive 2004/26/EC for engines for propulsion of locomotives

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 – PM – g/kWh
130 – 560	IIIA	3.5	4.0	-	-	0.2
>560	IIIA	3.5	-	0.5	6.0	0.2
>2000 & swept volume >51/cylinder	IIIA	3.5	-	0.4	7.4	0.2
130<	IIIB	3.5	4.0	-	-	0.025

Table A17.3 Emission limits in Directive 2004/26/EC for engines for propulsion of 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 – PM – g/kWh
130 < power	IIIA	3.5	4.0	-	-	0.2
130 <	IIIB	3.5	-	0.19	2.0	0.025

For small engines (37-75kW), the predicted technology required to meet Stage IIIA controls includes engine modifications, adoption of electronic engine control, improved fuel pumps and limited, un-cooled Exhaust Gas Recirculation (EGR). For larger engines which already utilise electronic engine control, the predicted technology required is engine modifications, common rail injection, air-air charge cooling and limited, un-cooled EGR. Further reductions for small engines (i.e. 18 - 37kW) are considered impractical (DfT, 2006).

For engines to meet Stage IIIB controls it is expected that diesel particulate filters (DPFs) will be fitted. To ensure reliable operation of DPFs, the use of low sulphur content fuels would be needed (approximately 10 mg/kg sulphur, which has been required across the EU since January 2011 according to the revised Fuel Quality Directive, 2009/30/EC) (DfT, 2006).

Stage IV controls are expected to force the adoption of Selective Catalytic Reduction (SCR) de-NOx after treatment systems in addition to DPFs. However, these systems are not effective if urea tanks are not filled up frequently (DfT, 2006).

In the current NAEI projections, the 2020 emission factors have been revised slightly for NOx and particulate matter relative to earlier versions and there is an 11% drop in activity rates forecast between 2020 and 2025.

A17.3 Beyond business as usual potential abatement measures

PM

The measure considered under PM abatement is retrofitting Diesel Particulate filters (DPF) to all pre-2015 railcars and locomotives. DPFs are assumed to be BAU for post-2015 trains under NRMM Stage IIIB limits.

Diesel Particulate filters can be used to significantly reduce emissions of particulates from diesel engines. Such a filter utilises a porous substrate, commonly in a honeycomb formation, with catalytically coated silicon carbide (SiC) particulate matter filters to physically trap soot particles. Very high PM removal efficiencies (>99%) are possible if low sulphur fuel is used (<0.5% S). An efficiency of 99% is assumed, in-line with DPFs assumed in on-road applications in the Road Transport MPMD chapter.

Capital costs are based on a report by the California Air Resources Board (CARB, 2006) and equate to approximately £50,000 per locomotive in 2011 prices. DPFs are assumed to have a lifetime of 8 years. Operating costs are assumed to be 3% of capital costs, based on the ratio of capital and operating costs of DPFs assumed in on-road applications in the Road Transport MPMD chapter.

Uptake is modelled on the basis of retrofitting DPFs to all pre-2015 trains, using a train life expectancy in the region of 30 to 35 years to estimate the potential proportion of the 2025/2030 fleet that dates to pre-2015 (DfT, 2006).

NOx

In February 2009, it was announced that under the Intercity Express Programme (IEP) hybrid technology would be deployed and put in service by the end of 2018[2]. Therefore, the uptake of hybrid drives is considered a measure being currently implemented under the business as usual scenario; although it is recognised that further uptake of this could be possible in the future[3]. Due to uncertainties over the maximum potential beyond business as usual uptake of hybrid drives, this has not been considered further.

There are currently plans to electrify new parts of the UK network as announced in a new funding commitment from the DfT[4]. Around 36% of the UK rail network that is open to passenger traffic is already electrified (DfT, 2011), whilst passenger services on other lines and freight services are operated by diesel-powered trains. High-speed electric trains have a higher carrying capacity than the equivalent diesel trains (DfT, 2007). Approximately two thirds of this electrified network is on the 25 kV AC overhead system, with the bulk of the remainder on the 750 V DC third rail system. Operating costs for switching from diesel to electric-power are affected by different availability levels, fuel consumption and future fuel prices as well as maintenance costs.

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[2] http://www.agilitytrains.com/assets/pdf/Agility_Trains_IEP_Preferred_Bidder_Announcement.pdf

[3] http://www.dft.gov.uk/pgr/rail/pi/rollingstock/rollingstockplan

[4] £9bn railway investment announced by coalition, http://www.bbc.co.uk/news/uk-18851907

Capital costs are a significant aspect of electrification. RSSB (2007) estimated the capital costs of electrifying an existing route in the range from £550k to £650k per single track kilometre, and annual operating costs of the additional infrastructure maintenance costs were estimated to be 0.4%-0.5% of the capital costs.

Further electrification of the UK rail network has been developed as a BBAU measure assuming the 25 kV AC overhead system. The routes considered to be electrified under BAU plans between 2013 and 2019 include the North West electrification programme, electrification of the Great Western Main Line to Cardiff and Swansea (and additionally to Oxford and Newbury), the South Wales valley lines, the North Transpennine route to Leeds and the Midlands Main Line. The rate of electrification in route-km/year of the BAU plans is assumed as the same rate of electrification in the BBAU measure which assumes further electrification from 2019. No specific routes are identified as part of this BBAU measure. Track kilometres are estimated from route kilometres from the average ratio implicit in RSSB (2007). Average capital and operating costs are taken from RSSB (2007). The lifetime of overhead electrical cable equipment is assumed to be 40 years (RSSB, 2007).

The NAEI emissions projections for the railway sector are recognised by AEA to be lacking in transparent detail of the train fleet, speeds, fuels and technologies. AEA's report on the UEP37 projection indicates that "a review of the rail projections to incorporate the impacts of the Directives, looking at future rail activity data (train km) and turnover in the rail/engine fleet [would improve the projections]". Without these data, a simple assumption that emissions from gas oil combustion is proportional with network route distances has been made.

PM, VOC, SO_2 and NOx emission reductions for an electric train over a diesel train are taken from a comparison of NAEI emission factors (grams of pollutant emitted per kWh of gas oil combusted) with those for the electricity sector in 2030 (derived from the NAEI UEP43 projections for the power sector). The emission reduction efficiencies are shown below in the table.

Table A17.4 Assumed emission reductions when switching from diesel trains to electric trains (2030)

Sector	$PM_{2.5}$ emission reduction	PM_{10} emission reduction	SO_2 emission reduction	NO_X emission reduction	NMVOC emission reduction
Intercity	95%	93%	65%	94%	99%
Regional	93%	92%	61%	92%	99%

Note: the above figures are calculated for 2030; those for 2025 differ due to different power sector emission factors. The main difference is that the SO2 emission reduction efficiency is much higher in 2030 due to that sector's reduced generation from coal.

A17.4 Summary of measures and costs

Table A17.5 summarises the estimated cost of each abatement technology for the rail sector. The costs in the summary table are based on the average cost of each abatement technology. The range of costs were summarised in Section 1.3 for NOx and dust abatement measures respectively. Table A17.6 presents the reduction efficiency of the abatement measures and the associated reduction in emissions.

Table A17.5 Summary of beyond BAU abatement measures for the rail sector for 2025 and 2030[1]

Abatement measure	Future uptake of measure (%)		Operating life (years)	Capital Costs (£k, 2011 prices)		Annual operating costs (£k, 2011 prices)		Total annualised costs (£kpa, 2011 prices)	
	2025	2030		2025	2030	2025	2030	2025	2030
Electrification	17%	31%	40	1,804,612	3,308,456	7,839	14,372	92,344	169,298
Diesel Particulate Filter retrofit	69%	54%	8	108,729	84,587	3,247	2,525	19,065	14,828

Note 1: A discount rate of 3.5% is considered in the analysis.

Table A17.6 Summary of beyond BAU abatement measures efficiency for rail sector

Abatement measure	Emission reduction efficiency (%)						Reduction in 2025 emissions (kt)						Reduction in 2030 emissions (kt)					
	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3
Electrification	91%	47%	93%	91%	99%	0%	2.43	0.06	0.06	0.06	0.81	N/A	4.46	0.11	0.11	0.11	0.81	N/A
Diesel Particulate Filter retrofit	0%	0%	99%	99%	0%	0%	0	0	0.27	0.26	0	N/A	0	0	0.21	0.20	0	N/A

Note 1: No baseline data has been provided for ammonia

A17.5 References

1. AEA, 2012. Personal Communication, Ben Pearsson, 24 May

2. AEA (2009), UK Emission Projections of Air Quality Pollutants to 2020, The results and assumptions of the 2007 to 2020 air quality pollutant emission projections, A report of the National Atmospheric Emissions Inventory AEA Group, Compiled by the UK Projections Team, AEA, March 2009.

3. CARB (2006) Summary of Current DPF Technology for Locomotive Applications in the United States and Europe. Provided by the Union Pacific Railroad, BNSF Railway and Southwest Research Institute. Accessed 10th August 2012 from http://www.arb.ca.gov/railyard/rrsubmittal/dpf_sum.pdf

4. DfT (2006), Regulatory Impact Assessment (RIA) on NRMM emissions, Department for Transport.

5. DfT (2011) Transport Statistics Great Britain 2010. Department for Transport. Available from www.dft.gov.uk

6. RSSB (2007), T633: Study on further electrification of Britain's railway network, Final Report, Rail Safety and Standards Board. http://www.rssb.co.uk/pdf/reports/research/T633_rpt_final.pdf

A18. Contents

A18.Non-Road Mobile Machinery (NRMM)

A18.1 Sector profile

Table A18.1 and Table A18.2 present the emissions for other mobile sources and machinery developed by AEA, based on DECC's UEP43 forecasts. Note that emissions from coastal shipping and rail are addressed in separate chapters.

Table A18.1 Emissions for other mobile sources and machinery for 2025

Source Name	Activity Name	Emissions (kt)					
		NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3
Agriculture - mobile machinery	Gas oil	4.34	0.02	0.41	0.54	1.45	0.00
Agriculture - mobile machinery	Petrol	0.00	0.00	0.00	0.00	0.12	0.00
Aircraft - support vehicles	Gas oil	0.53	0.01	0.03	0.03	0.20	0.00
House and garden machinery	DERV	0.57	0.00	0.02	0.02	0.03	0.00
House and garden machinery	Petrol	0.36	0.00	0.00	0.00	1.44	0.00
Industrial off-road mobile machinery	Gas oil	44.01	0.06	3.29	4.27	9.70	0.00
Industrial off-road mobile machinery	Petrol	1.34	0.00	0.01	0.01	8.38	0.00
	TOTAL	**51.15**	**0.09**	**3.76**	**4.87**	**21.33**	**0.00**

Table A18.2 Emissions for other mobile sources and machinery for 2030

Source Name	Activity Name	Emissions (kt)					
		NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3
Agriculture - mobile machinery	Gas oil	4.34	0.02	0.41	0.54	1.45	0.00
Agriculture - mobile machinery	Petrol	0.00	0.00	0.00	0.00	0.12	0.00
Aircraft - support vehicles	Gas oil	0.44	0.01	0.03	0.03	0.23	0.00
House and garden machinery	DERV	0.60	0.00	0.02	0.02	0.03	0.00
House and garden machinery	Petrol	0.38	0.00	0.00	0.00	1.50	0.00
Industrial off-road mobile machinery	Gas oil	46.96	0.06	3.50	4.55	10.32	0.00
Industrial off-road mobile machinery	Petrol	1.43	0.00	0.01	0.01	8.92	0.00
	TOTAL	**54.14**	**0.10**	**3.98**	**5.15**	**22.56**	**0.00**

As the tables above show, off-road mobile machinery are key sources for NOx, SO2, PM10, PM2.5 and NMVOCs.

It is noted here that AEA provided aggregated 2025 and 2030 emission and activity data for agricultural and industrial off-road machinery and aircraft support vehicles per stage control and 5 engine sizes. This dataset has been used for estimating the percentage uptake and percentage reduction efficiency of possible abatement measures developed for this sector, as it provides the necessary disaggregation required for all pollutants (except for SO_2). It is worth noting that no activity data have been provided for engines with a power >560kW.

A18.2 Business as usual policies and abatement measures

There are a number of Directives that regulate exhaust emissions from different types of NRMM. The original directive, 97/68/EC, covers diesel fuelled engines and became effective from 1 January 1999 (1 January 2001 for Stage II) for certain types of engines between 37-560 kW. The second directive, 2002/88/EC, covers spark ignition engines up to 18 kW for engines installed in handheld and non-handheld equipment. Stage I (and stage II) became effective in August 2004 with some exemptions for certain applications. The third directive, 2004/26/EC, covers diesel fuelled engines from 19-560kW for common NRMM and regulates emissions in three further stages:

- Stage III A covers engines from 19-560 kW including constant speed engines, railcars, locomotives and inland waterway vessels;
- Stage III B covers engines from 37-560 kW including, railcars and locomotives; and
- Stage IV covers engines between 56-560 kW.

Stage III A has been effective (place on the market) from 1 January 2006 for certain types of engines, stage III B from 1 January 2011 and stage IV will apply from 1 January 2014.

Directive 2000/25/EC[1] 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.

Table A18.3 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 – PM – g/kWh
130 – 560	I	5.0	1.3	9.2	0.54
75 – 130	I	5.0	1.3	9.2	0.7
37 – 75	I	6.5	1.3	9.2	0.85

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[1] Amended by Directive 2005/13/EC

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

Table A18.4 Emission limits in Directive 2002/88/EC for small spark ignition engines with a net power ≤19kW

Class / Category	Stage	Emission limit – CO – g/kWh	Emission limit – HC – g/kWh	Emission limit – NOx – g/kWh	Sum of HC and NOx – g/kWh
Class SH:1	I	805	295	5.36	-
Class SH:2	I	805	241	5.36	-
Class SH:3	I	603	161	5.36	-
Class SN:1	I	519	-	-	50
Class SN:2	I	519	-	-	40
Class SN:3	I	519	-	-	16.1
Class SN:4	I	519	-	-	13.4
Class SH:1	II	805	-	-	50
Class SH:2	II	805	-	-	50
Class SH:3	II	603	-	-	72
Class SN:1	II	610	-	-	50
Class SN:2	II	610	-	-	40
Class SN:3	II	610	-	-	16.1
Class SN:4	II	610	-	-	12.1

Note – For Stage II, NOx emissions for all engine classes must not exceed 10 g/kWh.

Table A18.5 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 – PM – g/kWh
130 – 560	IIIA	3.5	4.0	-	-	0.2
75 – 130	IIIA	5.0	4.0	-	-	0.3
37 – 75	IIIA	5.0	4.7	-	-	0.4
19 – 37	IIIA	5.5	7.5	-	-	0.6
130 – 560	IIIB	3.5	-	0.19	2.0	0.025
75 – 130	IIIB	5.0	-	0.19	3.3	0.025
56 – 75	IIIB	5.0	-	0.19	3.3	0.025
37 – 56	IIIB	5.0	4.7	-	-	0.025
130 – 560	IV	3.5	-	0.19	0.4	0.025
56 – 130	IV	5.0	-	0.19	0.4	0.025

For small engines (37-75kW), the predicted technology required to meet Stage IIIA controls includes engine modifications, adoption of electronic engine control, improved fuel pumps and limited, un-cooled Exhaust Gas Recirculation (EGR). For larger engines which already utilise electronic engine control, the predicted technology required is engine modifications, common rail injection, air-air charge cooling and limited, un-cooled EGR. Further reductions for small engines (i.e. 18 - 37kW) are considered impractical (DfT, 2006).

For engines to meet Stage IIIB controls it is expected that diesel particulate filters (DPFs) will be fitted. To ensure reliable operation of DPFs, the use of low sulphur content fuels is required (approximately 10 mg/kg sulphur, which has been required across the EU since January 2011 according to the revised Fuel Quality Directive, 2009/30/EC) (DfT, 2006).

Stage IV controls are expected to force the adoption of Selective Catalytic Reduction (SCR) de-NOx after treatment systems in addition to DPFs. However, these systems are not effective if urea tanks are not filled up frequently (DfT, 2006).

A18.3 Beyond business as usual potential abatement measures

The following abatement measures have been considered as beyond BAU measures for 2025 and 2030:

- Retrofitting of diesel particulate filters (DPFs) on existing diesel engines with a power < 37kW for industrial off-road machinery;

- Retrofitting of diesel particulate filters (DPFs) on existing diesel engines with a power >37kW for pre-Stage IIIB agricultural and industrial off-road machinery[2];
- Retrofitting of Selective Catalytic Reduction (SCR) de-NOx after treatment systems on existing diesel engines with a power >56kW for pre-Stage IV agricultural and industrial off-road machinery[3];
- Introducing new Stage control limits for diesel engines with a power <18kW for industrial off-road machinery, i.e. new engines that comply with a 7.5 g/kW emission limit for NOx and a 0.4 g/kW emission limit for PM. A review of the NRMM Directive considered the introduction of these emission limits for engines with a power <19kW[4] to align the Directive with US legislation (EC, 2007)[5]. These emission limits are similar to those required from Stage IIIA controls for smaller engines.

A18.4 Summary of measures and costs

Table A18.6 summarises the estimated cost of each abatement technology for the NRMM sector. The costs in the summary table are based on the average cost of each abatement technology. Table A18.7 presents the reduction efficiency of the abatement measures and the associated reduction in emissions.

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[2] Although this measure is applicable to diesel engines with a power >37kW, for this study this has only been applied to engines with a power >75kW as engines with a power 37-75kW represent 0.05% of total activity (TWh) from agricultural and industrial off-road machinery (derived from emission and activity data per stage control and 5 engine sizes provided by AEA).

[3] Although this measure is applicable to diesel engines with a power >56kW, for this study this has only been applied to engines with a power >75kW as there are no engines within the category 56-75kW for agricultural and industrial off-road machinery (derived from emission and activity data per stage control and 5 engine sizes provided by AEA).

[4] Threshold slightly higher than that considered in this study, i.e. <18kW.

[5] The technical report estimated that the major contribution to NOx and PM emissions was from engines in the power class 8 kW < p < 19 kW, while the emissions from the very small engines with a power < 8 kW was 0.04% of NOx and 0.1% of total PM emissions. The drawback identified for an emission limit for diesel engines with a power <19kW was that diesel engines with less than 8 kW would most probably be replaced by 4-stroke spark ignited engines. As the emission contribution of diesel engines with less than 8 kW is very low, and major manufacturers of diesel engines with less than 8 kW are European manufacturers the alignment for the 8-19 kW engine power class with US emission limits with no action for the 0-8 kW engine power class was the proposal preferred by industry.

Table A18.6 Summary of beyond BAU abatement measures for the NRMM sector for 2025 and 2030[1]

Abatement measure	Future uptake of measure (%)		Operating life (years)	Capital Costs (£k, 2011 prices)		Annual operating costs (£k, 2011 prices)		Total annualised costs (£kpa, 2011 prices)	
	2025	2030		2025	2030	2025	2030	2025	2030
Retrofitting DPFs to >37kW agricultural & industrial off-road machinery (gas oil)	50%	100%	5	8,223	8,223	436	436	2,257	2,257
Retrofitting DPFs to <37kW industrial off-road machinery (gas oil)	50%	100%	5	3,968	3,968	314	314	1,192	1,192
Retrofitting SCR to >56kW agricultural & industrial off-road machinery (gas oil)	50.0%	100%	8	8,212	8,212	438	438	1,633	1,633
Introducing Stage control limits for <19kW for industrial off-road machinery (gas oil)	50%	100%	Note 2	Note 2	Note 2	Note 2	Note 2	2,294	2,448

Note 1: The costs presented here are the average costs for each abatement measure (in case a measure was given a range of costs). A discount rate of 3.5% is considered in the analysis.

Note 2: No capital and operating costs are presented because a cost/tonne of pollutant abated was applied in the analysis.

Table A18.7 Summary of beyond BAU abatement measures efficiency for the NRMM sector

Abatement measure	Emission reduction efficiency (%)						Reduction in 2025 emissions (kt)						Reduction in 2030 emissions (kt)					
	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3
Retrofitting DPFs to >37kW agricultural & industrial off-road machinery (gas oil)	0.0%	0.0%	95.0%	95.0%	90.0%	-	0.00	0.00	0.80	1.04	2.43	-	0.00	0.00	0.22	1.11	2.60	-
Retrofitting DPFs to <37kW industrial off-road machinery (gas oil)	0.0%	0.0%	95.0%	95.0%	90.0%	-	0.00	0.00	1.30	1.71	0.57	-	0.00	0.00	1.38	1.81	0.56	-
Retrofitting SCR to >56kW agricultural & industrial off-road machinery (gas oil)	70.0%	0.0%	0.0%	0.0%	0.0%	-	10.89	0.00	0.00	0.00	0.00	-	11.61	0.00	0.00	0.00	0.00	-
Introducing Stage control limits for <19kW for industrial off-road machinery (gas oil)	46.2%	0.0%	81.2%	81.2%	12.2%	-	3.56	0.00	0.68	0.96	0.89	-	3.80	0.00	0.73	1.02	0.95	-

A18.5 References

1. NAEI emission projections to 2030 (UEP43 / 2009 base NAEI)
2. EC (2007), 2007 Technical Review of the NRMM Directive 1997/68/EC as amended by Directives 2002/88/EC and 2004/26/EC, European Commission, Joint Research Centre, 15 Draft Final report, December 2007. http://ec.europa.eu/enterprise/mechan_equipment/emissions/2007tecrew_dfr.pdf
3. Entec (2003), Revision of cost curve for NOx, March 2003, A report for Defra.
4. DfT (2004), RIA on proposed new emission limits for off-road engines, Department for Transport.
5. DfT (2006), Regulatory Impact Assessment (RIA) on NRMM emissions, Department for Transport.
6. DfT (2006b), Final RIA: New emission standards for agricultural and forestry tractors, Department for Transport.

A19. Contents

A19.Road Transport

A19.1 Sector profile

Road transport is the primary method of transport used by the majority of the population, as well as being a key mode of freight transport. The number of passenger cars and light goods vehicles (LGVs) licensed in the UK has risen steadily since the 1950s to around 30 million vehicles in 2010; there are approximately a further 5 million other licensed vehicles (DfT, 2011). Motor vehicle traffic volume in 2009 was 313 billion vehicle miles, which is more than 10 times the volume in 1949 (DfT, 2011). The Department for Transport (DfT) forecasts that traffic volume will continue to grow following the long term historic growth trend. The two primary fuel types used in road vehicles are petrol and diesel.

Emissions to air from road transport arise both as exhaust gases from the combustion of fuels and from the wear on the vehicle. Exhaust gas pollutants include primarily nitrogen oxides (NO_X), particular matter (PM), volatile organic compounds (VOC), carbon monoxide (CO) and carbon dioxide (CO_2). Other gaseous pollutants include nitrous oxide (N_2O) and methane (CH_4) which is emitted in particular from the small number of vehicles fuelled with liquefied petroleum gas (LPG) and also compressed natural gas (CNG)[1]. Due to stringent legislation limiting the sulphur content of petrol and diesel, exhaust SO_2 emissions from road transport are very low.

Emissions of PM comprise both exhaust emissions (primarily from diesel vehicles) and wear of tyres, brakes, and to a lesser extent clutches and other vehicle parts. Tyre and brake wear is projected in the NAEI to form the majority component of total PM emissions from road transport in the period of focus (2025 to 2030) due to the forecast growth in traffic volumes. The abrasion of vehicles' tyres on road surfaces also leads to road surface wear in the form of further PM emissions; this emission is not considered in the road transport sector, and is considered in the road dressing sector analysis. An additional contribution to ambient concentrations of PM, but not an emission source itself *per se*, is the resuspension of dust by e.g. passing vehicles.

The NAEI (base 2009) emission projections for road transport (April 2012) are based on DECC's UEP43 forecasts and DfT's traffic projections from December 2011 and, for London, traffic projections from Transport for London from December 2010. It should be noted that the emission projections used do not account for recent improved understanding of real-world NO_X emissions from heavy duty vehicles (HDVs) fitted with de-NO_X after-treatment in urban drive cycles. However, the NO_X emission factors used in the NAEI have recently been updated to follow the COPERT 4 factors. The projections for 2025 and 2030 are shown in Table A19.1. The road transport emissions projections that have been provided to AMEC are additionally disaggregated by vehicle emission (Euro) standard.

Key sources of NO_X emissions from the road transport sector are passenger cars (primarily diesels), LGVs and HDVs, which comprise heavy goods vehicles (HGVs) and buses. As noted above, key sources of PM *emissions* are non-exhaust components tyre wear, brake wear and road abrasion, and passenger car exhausts. Key sources of NMVOC emissions are passenger cars and diesel LGVs.

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[1] http://rael.berkeley.edu/sites/default/files/very-old-site/Climatic_Change.pdf

Table A19.1 NAEI road transport emissions projections

SnapID	Source	Activity	2025 emissions (kt)					2030 emissions (kt)				
			NO_X	SO_2	$PM_{2.5}$	PM_{10}	NMVOC	NO_X	SO_2	$PM_{2.5}$	PM_{10}	NMVOC
0701	Cars	Petrol	11.9	0.10	0.22	0.23	10.8	12.7	0.10	0.24	0.25	11.9
0701	Cars	DERV (diesel)	91.3	0.16	0.37	0.39	11.7	84.5	0.15	0.26	0.27	12.4
0702	LGV	Petrol	0.7	0.00	0.00	0.00	0.5	0.8	0.00	0.00	0.00	0.6
0702	LGV	DERV (diesel)	31.2	0.11	0.11	0.12	5.9	32.6	0.12	0.10	0.10	8.2
0703	Rigid HGV	DERV (diesel)	5.1	Included below	0.04	0.05	0.1	4.7	Included below	0.04	0.04	0.1
0703	Articulated HGV	DERV (diesel)	3.4	0.12	0.04	0.04	0.0	3.4	0.12	0.04	0.04	0.0
0703	Buses	DERV (diesel)	5.0	0.02	0.04	0.04	0.0	3.1	0.02	0.02	0.02	0.0
0704	Mopeds and Motorcycles	Petrol, 2 stroke	0.0	Included below	0.00	0.00	0.5	0.0	Included below	0.00	0.00	0.5
0705	Motorcycles	Petrol, 4 stroke	0.8	0.00	0.01	0.01	2.1	0.8	0.00	0.01	0.01	2.1
07	**SUBTOTAL EXHAUST**		**149.4**	**0.50**	**0.83**	**0.87**	**31.7**	**142.8**	**0.52**	**0.71**	**0.74**	**35.9**
0707	Tyre wear	(All vehicles)			4.08	5.83				4.33	6.19	
0707	Brake wear	(All vehicles)			2.30	5.75				2.44	6.09	
	Road abrasion				3.25	6.02				3.44	6.37	
07	**SUBTOTAL EXHAUST & WEAR**		**149.4**	**0.50**	**10.5**	**18.5**	**31.7**	**142.8**	**0.52**	**10.9**	**19.4**	**35.9**
	Road transport resuspension				6.08	20.97				6.08	20.97	

A19.2 Business as usual policies and abatement measures

Exhaust emissions from road transport vehicles have been subject to legislative controls at an EU level since the early 1990s which are referred to as the ‘Euro standards’. Since the introduction of the first controls (Euro 1/I) in 1992 for passenger cars and HDVs and 1994 for LGVs, increasingly stringent emission limit values have been placed on exhaust emissions of new vehicles as part of the type approval process.

Light duty vehicles

The road transport emission projections take into account the most recent Euro standards on light duty vehicles (LDVs) – Euro 5 and Euro 6 – set out in Regulation (EC) No 715/2007[2] as amended by Regulation (EU) No 566/2011. New LDVs entering the market now must meet the Euro 5 standard. Euro 6 further tightens the NO_X limit values for diesel cars and LGVs; new cars (LGVs) first type approved from September 2014 (2015) must meet the Euro 6 standard, and all new LDVs entering the market must comply with Euro 6 one year after these dates. The emission limits for Euro 5 and Euro 6 are set out in Table A19.2.

Table A19.2 Euro 5 and Euro 6 emission limits

Vehicle type	Category	Class	Mass (tonnes)	NO_X (mg/km)		NMHC (mg/km)	CO (mg/km)	PM (mg/km)
				Euro 5	Euro 6	Euro 5 & 6	Euro 5 & 6	Euro 5 & 6
Petrol Car	M	-	(All)	60	60	68	1,000	5
Petrol LGV	N_1	I	≤ 1.305	60	60	68	1,000	5
	N_1	II	1.305 – 1.760	75	75	90	1,810	5
	N_1 and N_2	III	≥ 1.760	82	82	108	2,270	5
Diesel car	M	-	(All)	180	80	-	500	5
Diesel LGV	N_1	I	≤ 1.305	180	80	-	500	5
	N_1	II	1.305 – 1.760	235	105	-	630	5
	N_1 and N_2	III	≥ 1.760	280	125	-	740	5

It is anticipated that the tighter NO_X standards for Euro 6 diesel cars and LGVs are likely to require catalyst-based technologies such as SCR or lean NO_X traps (LNT). AEA (2007) state that an allowance was made for the possible failure of a small proportion of these technologies in the fleet, in-line with an assumed failure rate for petrol cars with three-way catalysts. A failure rate of 5% p.a. was assumed for NO_X emissions from Euro 6 diesel cars and LGVs. A smaller reduction in emissions during the cold start phase was also assumed by AEA for these vehicles to allow for the influence of catalyst light-off time, i.e. the period during when the catalyst is warming up and the NO_X exhaust after-treatment systems are not fully effective. In general, AEA assume that the Euro 6 emission standards deliver the expected emission reductions.

Due to the turnover of the fleet, by 2025 and 2030 approximately 85% to 90% and 99% respectively of the vehicle kilometres driven by LDVs are projected to be Euro 6 compliant vehicles.

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[2] Regulation (EC) No 715/2007 of the European Parliament and of the Council of 20 June 2007 on type approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6) and on access to vehicle repair and maintenance information. OJ L171 of 29.6.2007, p.1-16.

Heavy duty vehicles

The road transport emission projections take into account the most recent legislation introducing Euro VI limit values for HDVs, i.e. HGVs and buses and coaches from Regulation (EC) No 595/2009[3]. Euro VI standards for HDVs are expected to require secondary PM and NO_X after treatment abatement measures. In general, AEA assume that the Euro VI emission standards deliver the expected emission reductions.

Due to the turnover of the fleet, by 2025 and 2030 99% and 100% respectively of the vehicle kilometres driven by HGVs are projected to be Euro VI compliant vehicles. For buses, a greater proportion are expected to still be Euro V compliant vehicles: by 2025 and 2030, 90% and 98% of buses are projected to be Euro VI compliant vehicles

Non exhaust PM emissions

No business-as-usual policies are expected to address the non-exhaust PM emissions from e.g. tyre and brake wear. As such, non-exhaust PM emissions are expected to rise over time in-line with the forecast growth in vehicle kilometres driven.

Other assumptions of the updated projections

The road transport emission projections also incorporate additional assumptions: diesel car sales are assumed to remain at 50.5% until 2016, falling to 43% by 2020 and remaining static thereafter; the impacts of the London Low Emission Zone are taken into account. A level of business as usual take-up of electric cars is included and they are assumed to operate solely in urban areas with zero tailpipe emissions.

A19.3 Beyond business as usual

Emission reductions in the road transport sector do not necessarily need to focus on the largest sources of emissions because reduction potentials can be higher, as well as more feasible in terms of implementation, in captive fleets (e.g. HGVs and buses). The choices of abatement measures have been chosen to reflect this.

19.3.1 Abatement techniques

Both technical and non-technical abatement measures for the reduction of NOx, PM, CO_2 and NMVOCs from road transport have been considered for 2025 and 2030, and are listed in Table A19.3, and described in more detail along with the assumptions in the subsections of section A20.3.2. Cross media impacts on SO_2, CO, CO_2, N_2O, CH_4 and NH_3 are also considered. The listed measures include some to address the non-exhaust brake wear PM emission component. A number of other potential measures to address the non-exhaust PM emission component

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[3] Regulation (EC) No 595/2009 of the European Parliament and of the Council of 18 June 2009 on type-approval of motor vehicles and engines with respect to emissions from heavy duty vehicles (Euro VI) and on access to vehicle repair and maintenance information and amending Regulation (EC) No 715/2007 and Directive 2007/46/EC and repealing Directives 80/1269/EEC, 2005/55/EC and 2005/78/EC. OJ L188 of 18.07.2009, p.1-13.

were also investigated but insufficient evidence was identified. These are detailed further below in this section, including other measures that were considered but not quantified.

Table A19.3 Summary of abatement measures for the transport sector

Measure Reference	Measure	Additional scenarios
T3	Retrofitting pre-Euro VI HDVs with diesel particulate filters (DPF)	
T4	Introducing new hydrogen (H_2) buses instead of new diesel buses	
T5.1, T5.2	Introducing new hybrid diesel electric buses instead of diesel buses	Separately considering replacement of existing pre-Euro VI bus fleet
T6	Replace existing pre-Euro 6 LGVs with hybrid LGVs	
T7.1, T7.2	Replace existing pre-Euro 6 cars with hybrid cars	Separately considering petrol and diesel cars
T8.1, T8.2, T8.3, T8.4	Retrofitting wet braking systems	Separately considering HGVs, LGVs, cars and buses
T11, T12	Replace petrol and diesel cars with electric cars	Includes both consideration of replacement of existing pre-Euro 6, and new electric cars instead of new Euro 6
T13	Replace diesel LGVs with electric LGVs	Includes both consideration of replacement of existing pre-Euro 6, and new electric LGVs instead of new Euro 6
T14	Replace buses with electric buses	Includes both consideration of replacement of existing pre-Euro VI, and new electric buses instead of new Euro VI
T15	Road spraying	
N1	Shifting a fraction of road freight to rail freight	
N2.1, N2.3, N2.4	Eco-driving	Separately considering eco-driving training schemes for existing car drivers from schemes for LGVs and HGVs.
N3	Motorway speed limit enforcement	
N4	Downsizing petrol cars	

‘Tx.x’ measures are technical measures; ‘Nx.x’ measures are non-technical measures.

The number of non-technical abatement measures included for road transport in the MPMD is limited to four due to data scarcity (particularly regarding abatement efficiencies), but it is noted that a number of non-technical measures could potentially yield high abatement efficiencies. Such measures include, but are not limited to:

- **Road pricing**. Road pricing has been identified in a report for the Dutch Government as the most cost-effective option that could be taken for reducing Dutch national totals of NOx and PM emissions and ambient air concentrations (MNP, 2007). Road pricing was considered in the AQSR for the UK (Defra, 2007); however only emission reductions were calculated (i.e. no costs were presented). The Institute for Fiscal Studies has published an analysis of motoring taxation in the UK and concludes that there is a compelling case for road pricing (IFS, 2012).

- **Smarter choices**. ‘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.’ Taken from the Department for Transport website http://www.dft.gov.uk/topics/sustainable/smarter-choices;

- Utilising **home shopping delivery** to reduce domestic car journeys; and

- **Restrictions of vehicle use in high pollution episodes**. Although this measure may not greatly aid compliance with national emission ceilings, it would improve compliance with local air quality limit values.

Of the technical measures presented in this analysis, no discussion is presented on the appropriate method for implementation of the measures. A non-technical measure may be needed in parallel with a technical measure in order to incentivise uptake of the measure. This market stimulation may be in the form of a grant or loan scheme, advertising campaign or may be a combination of other, smaller benefits such as reduced parking charges. Although small, there may be an additional cost associated with the setting up and administration of any incentivisation scheme; these have not been considered in this analysis.

Selective Catalytic Reduction (SCR)

SCR was previously considered as a measure in the MPMD for 2020. However, in the timescales of 2025 and 2030, the majority of the HDV fleet will already have SCR fitted under business as usual in order to meet the Euro V and VI standards, such that SCR is no longer considered in the MPMD for 2025 and 2030.

Improving road surface design to reduce road surface wear

This is considered in the road dressings sector.

Conversion to Compressed Natural Gas (CNG)

Conversion of HDVs to CNG was previously considered as a technical measure in the MPMD for the years up to 2020. For the consideration of years 2025 to 2030 – in which, as identified above, the vast majority of HDVs will already meet Euro VI standard – the relative benefits of CNG compared to business-as-usual emission performance of HDVs is expected to be only marginal. Although CNG might be otherwise expected to remain beneficial in terms of delivering reduced CO_2 emissions compared to diesel, the total cross media impact on greenhouse gases is complex due to a heavy CH_4 penalty, although it is possible this could be reduced or eliminated by 2030. INFORM (2000) suggests that “greenhouse gas emissions from CNG buses appear to be similar to those from diesel buses on a total fuel cycle basis, even though they emit more methane. Natural gas buses have inherently lower carbon dioxide emissions than diesel buses.”

Improved tyre materials to reduce tyre wear

Research was undertaken on exploring the potential for alternative and new tyre materials that could reduce PM emissions from tyre wear. This included a literature review and consultation[4] with a leading manufacturer via the Highways Agency. However, insufficient evidence was gathered and made available by manufacturers for the production of a measure for the database, although such measures may be considered in future work.

Potential future Euro standards

As identified above, the vast majority of the light and heavy duty fleets will comprise vehicles compliant with the latest Euro standards in 2030 (Euro 6 / Euro VI). Consideration has been given to the possibility of potential future Euro 7 / VII standards. No formal discussions or negotiations are currently taking place in relation to possible future Euro standards. It is noted that IIASA have included a possible Euro 7 / VII standards as a future measure in place from 2020 in a report in support of the revision of the Air Quality Directive.[5] In that report no cost data are presented , but it is assumed that the hypothetical Euro 7 standard reduces NOx emissions by 20% compared to Euro 6 (with unclear impact on PM emissions) and that the hypothetical Euro VII standard reduces NOx emissions by 30% compared to Euro VI with no impact on PM emissions. However, the IIASA report does state that "efficiencies and costs are not related to specific technologies" and are "placeholder values". As such given that this is hypothetical only, and no specific technologies are identified for meeting reduced NOx emission limits, no measure is included in the database on this.

Second generation biofuels

Whilst there is potential for biofuels to be used in a wide range of sectors, a particular focus for their use is in road transport, due to the dependency in this sector on crude oil derived fuels, the anticipated growth in the sector and because there are few mature technologies available to significantly reduce CO_2 emissions. In December 2011 the Government implemented the provisions of the Renewable Energy Directive related to transport by amending the existing Renewable Transport Fuels Obligation (RTFO). In the short term and using current technologies, the DfT suggest that "*the UK could produce enough biofuels for around 2.5% of our road transport fuel needs whilst still leaving some land available for other bioenergy crop uses*"[6]. The RTFO sets out targets for biofuel use by volume, increasing to 5% by April 2013. The latest RTFO verified report[7] shows that the UK did not meet the 2010/11 obligation period 3.5% volume target; 3.3% of total road transport fuels were biofuels.

There have however been concerns with first-generation biofuels, which are made from food crops, related to:

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[4] Personal communication late May 2012.

[5] http://circa.europa.eu/Public/irc/env/cafe_baseline/library?l=/thematic_strategy/01-meetings/01-stakeholder_expert/2012_06_21/documents/tsap-transport-20120612p/_EN_1.0_&a=d

[6] http://webarchive.nationalarchives.gov.uk/20091009153230/
http://www.dft.gov.uk/pgr/roads/environment/rtfo/289579?page=5

[7] http://assets.dft.gov.uk/statistics/releases/verified-rtfo-biofuel-statistics-2010-11/year-3-verified-report.pdf

- Reduced feedstock for livestock farming driving up costs to farmers and consumers for meat and dairy products.

- Competition for land – There is more competition for suitable land resulting in less land being available for food production and industrial applications (e.g. pharmaceuticals). As an indirect consequence there has been a greater use of 'marginal' land (e.g. not ideally suited for farming) rather than being left as set-aside land causing further erosions to the natural landscape and ecosystems.

- Losses of biodiversity and natural landscape – Forests converted into land for biofuel have resulted in increases in emissions associated with deforestation (e.g. loss of carbon sink) and biodiversity loss.

This has led to a re-evaluation in the UK and the EU over the use of biofuel. In July 2008, the Gallagher Review was published which undertook a "Review of the Indirect Effects of Biofuel"[8]. This led the UK Government to adjust its position on biofuels. The EU Biofuels Directive still has a target of 10% of transportation fuels to be derived from biofuels by 2020, but requires that all EU biofuel meet 'cross compliance' environmental rules. If certain biofuels do not meet these criteria, they will not count towards country targets or be eligible for tax exemption or similar financial support. There is however no requirement for obligatory certification of all biofuel used in the EU.

This has led to an increased emphasis on second-generation biofuels where some of the associated problems with first-generation biofuels can be mitigated. Second generation biofuels involves "using lignocellulosic materials including agricultural waste (corn stalks, wheat straw, seed husks), woody biomass (e.g. forest residues)" (IEA, 2006) and algae. Some of the advantages of using these sources include:

- Lignocellulosic conversion enables bioethanol to be produced from a wider range of plant material, including non-food feedstock which avoids competition with feedstock for livestock farming and food.

- Biofuels are compatible with existing engine technology and fuel distribution infrastructure. Second generation production can benefit from existing infrastructure developed for first generation biofuel.

- Second generation has a 75-95% GHG reduction compared to petroleum gasoline[9].

- Some second generation fuels can offer better engine performance and the quality of the fuel is better than first generation biofuel[10].

- May use less land e.g. a new genetically modified variety of sugarcane is able to produce up to 200 tonnes of biofuels per hectare. In this case, plant science could triple production volumes per hectare of land relative to unmodified sugarcane.

An example of the benefits and current constraints of second generation biofuel is described in Box 1.

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[8] http://www.dft.gov.uk/rfa/reportsandpublications/reviewoftheindirecteffectsofbiofuels.cfm

[9] IEA Report on 1st- to 2nd-Generation Biofuel Technologies - 09 March 2009 - by Ralph Sims, Michael Taylor, Jack Saddler and Warren Mabee - http://www.renewableenergyworld.com/rea/news/article/2009/03/ieas-report-on-1st-to-2nd-generation-biofuel-technologies

[10] Biofuels: The Next Generation - http://www.euractiv.com/en/energy/biofuels-generation/article-165951

Box 1 Biofuel from Algae (Extracts from sources)

"Algae as a potential source of biodiesel doesn't compete with food crops in contrast to today's conventional biofuels. Indeed, waterborne algae hold much promise. The tiny marine plant needs only water (salt or fresh), the energy of the sun, nutrients and carbon dioxide (CO_2) to produce vegetable oil through photosynthesis. Some strains yield at least 15 times more vegetable oil per hectare than crops commonly used for biofuels, such as rapeseed, palm or soya. Some algae species grow so fast that they double their size three or four times in one day. That means they can be harvested frequently, an advantage over crops which are only harvestable a few times a year. Moreover, installations to grow algae can be located in areas unsuitable for agriculture, even deserts.

However, significant hurdles must be overcome before algae-based biofuel can be produced cost-effectively in the large volumes that would be needed to make a difference in the world's overall supply of transport fuel. To work on a large commercial scale, the process calls for huge amounts of water, which could limit where it is produced. There is no tried and tested method to harvest algae efficiently in large volumes and research must still be done to identify the best strains for producing oil" (Shell 2009).

"As part of the Carbon Trust Advanced Bioenergy Accelerator, the Carbon Trust intends to make a multi-million pound investment to support the development and commercialisation of microalgae biofuel technologies that have the potential to reduce carbon dioxide emissions. Following an extensive programme of work over the last year, analysing the algae biofuel opportunity and developing an appropriate R&D investment strategy to overcome these challenges, the Carbon Trust intends to fund R&D into microalgae derived transport fuels through the Algae Biofuels Challenge, ABC. The Carbon Trust are putting £20m in funding into a demonstration plant with the aim of operation by 2015" (Carbon Trust, 2009).

Sources: Shell (2009) http://www.shell.com/home/content/innovation/alternative_energy/biofuels/biofuels.html; Carbon Trust (2009) http://www.carbontrust.co.uk/technology/directedresearch/algae.htm

Emissions

Second generation biofuels have a more favourable GHG balance than existing biofuels. EURACTIV (2008) suggests that "*cellulose ethanol could produce 75% less CO_2 than normal petrol, whereas corn or sugar-beet ethanol reduces CO_2 levels by just 60%*" and that for diesel, "*biomass-to-Liquid (BtL) technology could [reduce] CO_2 emissions by 90%, compared with 75% for currently-available biodiesel*".

There is a lack of studies on the emissions reductions potential for other pollutants and therefore the reductions presented in the section refer mostly to studies on first generation fuels. It is assumed that these emissions are comparable. However, with adjustments to engines to incorporate biofuels, there is potential for any increases in emissions to be mitigated without compromising the reduction of emissions in other pollutants that are possible with second generation biofuel.

For example the Royal Society Biofuel report (2008)[11], suggests "*Volkswagen has developed a combined combustion system coupled to fuel derived from the Fischer-Tropsch process. Opportunities also exist to use biofuels in electric-hybrid vehicles. The key issue here is whether these biofuels can be used to deliver the European Union's Euro 5 and 6 vehicle emissions standards, which require much greater reductions in air pollutants such as NO_x and particulate matter from petrol and diesel vehicles*".

Lapuerta *et al* (2008) provided an extensive literature review of studies concerning the performance and emissions associated with first generation biofuel relative to diesel. The results were shown to vary depending on various factors such as the fuel mix concentration, if full power is required, type of engine and operating conditions. However a general consensus can be made based on the estimated share of literature (in percentage of number of

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[11] Sustainable biofuels: prospects and challenges (The Royal Society – Jan 2008) http://royalsociety.org/displaypagedoc.asp?id=28914

publications) on whether performance and emissions would increase, stay the same or decrease relative to standard diesel (see Table A19.4). SO_X emissions from road transport are not considered significant in this report.

Table A19.4 General consensus on performance and emissions associated with biofuel relative to diesel

Performance / pollutant	Proportion of studies indicating an increase	Proportion of studies indicating no change	Proportion of studies indicating a decrease	Proportion of studies indicating synergies
Effective power	-	2%	**96%**	2%
Brake-specific fuel consumption	**98%**	2%	-	-
Thermal efficiency	8%	**80%**	4%	8%
NOx emissions	**85%**	10%	5%	-
PM emissions	3%	2%	**95%**	-
THC emissions	1%	3%	**95%**	1%
CO emissions	2%	7%	**90%**	1%

Source: Lapuerta et al. (2008)

However if we are to consider certain factors about these studies, it is possible to show that some of the negative aspects of using biofuel can be mitigated by the time second generation fuels become commercially available. These are out outlined below in Table A19.5 along with emission reduction percentages.

Table A19.5 Emissions reductions and possible mitigation measures for improving performance and NOx emissions

Performance / pollutant	Increase/ decrease	Range	Reasons and possible mitigation (where relevant)
Effective power	Decrease	-	Some second generation biofuels are expected to have a better performance relative to first generation biofuel. Biodiesel performance may only be compromised if the accelerator is fully pressed down. In most cases the accelerator is not fully pressed with engines oversized and therefore power output is likely to be the same as with diesel fuel.
Brake-specific fuel consumption	Increase	-	Some second generation biofuels are expected to have better performance relative to first generation biofuel and therefore may result in lower fuel consumption.
Thermal efficiency	Same	-	-
NOx emissions	Increase	1.2-20%	This depends on the fuel blend and engine conditions. For example, studies observed an increase in NOx emissions of 3.7% with the 20% blend while only a 1.2% with the 30% blend. Police et al. measured increases around 20%, while Rantanen et al. found 4–10% increases, in both cases operating heavy-duty engines. Two types of measures have been proposed to eliminate the increase in NOx emissions. Delaying the injection timing should eliminate the NOx emissions without comprising PM reductions. Modifications of fuel mix and engine load/size will also reduce NOx emissions (as demonstrated by the range).
PM emissions	Decrease	50-91%	This reduction is mainly caused by reduced soot formation and enhanced soot oxidation due to the oxygen content and the absence of aromatic content in biodiesel. The choice of biofuel sources and cold temperatures can affect the scale of reductions.
THC emissions	Decrease	60-70%	-

Performance / pollutant	Increase/ decrease	Range	Reasons and possible mitigation (where relevant)
CO emissions	Decrease	50%	Load conditions have been proved to have a remarkable effect on CO emissions. Most authors report CO decreases when using biodiesel except at low-load conditions

Source: Lapuerta et al. (2008).

Costs

The UK National Non-Food Crop Centre (NNFCC) estimated that a (second generation) Biomass-To-Liquid (BTL) processing plant would cost about 4 times as much as a 250,000 tonne (first generation) biodiesel plant (£50m) for the same amount of fuel[12].

The IEA's Report on 1st- to 2nd-Generation Biofuel Technologies (2009) indicates that the *"commercial-scale production costs of 2nd-generation biofuels to be in the range of US $0.80 - 1.00/liter of gasoline equivalent (lge) [US $3.02-$3.79 per gallon] for ethanol and at least US $1.00/liter [$3.79 per gallon] of diesel equivalent for synthetic diesel. This range broadly relates to gasoline or diesel wholesale prices (measured in USD /lge) when the crude oil price is between US $100-130 /bbl. The present widely fluctuating oil and gas prices therefore make investment in 2nd-generation biofuels at current production costs a high risk venture*".

However, Defra (2008)[13] suggests that the cost of second generation biofuels will fall much more than first generation fuels. Two main factors explain this:

- Second generation technology is at an earlier stage of development and is therefore likely to benefit from greater learning curve cost reductions than first generation technology; and
- Feedstocks account for a significantly smaller share of total costs for second generation fuels (feedstock costs for first generation fuels are estimated to be about 80% of costs) and therefore there is opportunity for processing costs to fall for second generation fuels.

Based on analysis by McKinsey (2007)[14] the report estimates that the cost of cellulosic ethanol will fall by over 50% from 2002 to 2030. Cost falls for biodiesel are expected to be just 13%. Table A19.6 below sets out volumetric costs for different biofuels in 2002 and 2030 and the percentage reduction over this period.

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[12] http://news.bbc.co.uk/1/hi/sci/tech/5353118.stm

[13] Estimating the Cost-Effectiveness of Biofuels – Defra Economics Group (April 2008) http://www.defra.gov.uk/environment/climatechange/uk/energy/renewablefuel/pdf/biofuels-080414-2.pdf

[14] This is an unreferenced study used within the Defra report

Table A19.6 Biofuel production costs in 2002 and 2030 (€/litre)

Type	Cost in 2002	Cost in 2030	% fall
Biodiesel	0.47	0.41	-13%
Grain ethanol	0.4	0.37	-8%
Sugar-cane ethanol	0.27	0.22	-19%
Cellulosic ethanol	0.47	0.22	-53%

Source: Estimating the Cost-Effectiveness of Biofuels – Defra Economics Group (April 2008)

Supply concerns

Second generation biofuels are not currently produced on a commercial scale, and the timescales with which commercial production may develop are unclear. Shell UK suggest "*second generation biofuels will not be available in significant commercial quantities for the next five to ten years*"[15]. There are two key factors in addition to cost holding back the commercial production of second generation biofuels:

- Technological breakthroughs: Key developments are needed on enzymes, pre-treatment and fermentation in order to make processes more cost- and energy-efficient. Whereas with first-generation biofuels, natural oils are extracted from the plants to produce fuel, second-generation processes, working with waste and 'woody' materials require complex catalysis and chemical alteration procedures to create the oils in the first place.

- Infrastructure needs: The commercialisation of second-generation biofuels will require the development of a whole new infrastructure for harvesting, transporting, storing and refining biomass. Many studies assume that the majority of biofuel infrastructure common to first generation biofuel will be in place and hence reduce the time lag for the commercial availability of second generation technologies. However, given the issues over sustainability and concerns over competition with food, infrastructure in the UK for first generation biofuel are likely to be significantly underdeveloped.

Conclusion

So far, only certain small experimental or demonstration plants exist, and production is not yet near to being started on a commercial level. Given that these methods are still under development and that there is high uncertainty regarding the timeline for implementation, expected costs and impacts on emissions of air pollutants, it is not considered appropriate at this stage to include second generation biofuels as a measure within the database.

19.3.2 Methodology/assumptions

The vehicle fleet size and composition up to 2030 have been provided by AEA[16] and are shown in Table A19.7.

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[15] http://www.shell.co.uk/home/content/gbr/products_services/on_the_road/card_services/shell_fuel_card_for_business/eurosh ell_trucks_and_coaches/crt/shell_fuels/bio_fuels.html

[16] Personal Communication with AEA Technology, 31st May 2012

Table A19.7 Vehicle fleet numbers and composition

Vehicle Type	2025 (000s)	2030 (000s)
Petrol cars	13,249	13,993
Diesel cars	11,162	10,921
Petrol LGV	68	76
Diesel LGVs	3,615	4,068
Rigid HGV	202	212
Artic HGV	114	123
Buses	126	127
Motorcycles 2st	27	AMEC assumed same as 2025
Motorcycles 4st	1,026	AMEC assumed same as 2025
Total	**29,590**	**30,574**

The data in Table A19.7 have been provided annually to 2030, further split by Euro standard. From these data, AMEC has estimated the number of new vehicles projected to be bought each year and the number of vehicles each year that can be considered to be ‘existing’ vehicles, assuming that new vehicles bought each year replace older Euro standard vehicles. AEA provided data which has been used as a proxy for fleet turnover, in terms of % of kilometres driven by each Euro standard category for each vehicle type, for five year intervals; AMEC has interpolated linearly between these years.

DfT provided pre-tax pump-price forecasts of unleaded petrol and ultra low sulphur diesel to 2030 from their Road Fuel Price Forecasting Model, which is understood to be based on the DECC Oil Price projections[17]; prices from Scenario 2 have been adopted[18]. The pre-tax price of petrol in 2030 under Scenario 2 is projected to be 65.23 pence per litre. It is recognised however that fuel prices are volatile and may go up or down.

Diesel Particulate Filters (DPF) – Measure T3

Diesel particulate filters (DPFs) are end-of pipe exhaust measures that can be retrofitted to older, more polluting vehicles to abate particulate emissions. Only full wall-flow filters are considered; partial filters are not considered due to their low abatement efficiencies. Full wall flow filters typically abate 99% of $PM_{2.5}$ and PM_{10}[19], with cross-

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[17] Personal communication with DfT, 14th May 2012

[18] Scenario 2 – Timely investment and moderate demand:
- The global recession continues to 2010 and low demand keeps prices low in the short term.
- In the medium term, global economic growth picks up and pushes up demand for energy.
- Investment is made in a timely manner. High demand means that more expensive oil resources need to be developed. This leads to increases in prices over the period.
- Prices continue to rise until 2030, reflecting that more expensive resources such as oil shales will need to be developed.

[19] Personal Communications with DfT, 1st Feb 2012 and Defra 21 Feb 2012

media simultaneous reductions of 90% of both VOCs and CO. It is known that DPFs using oxidation catalysts lead to an increase in the proportion of NOx emitted as NO_2. In order to regenerate the particulate trap (i.e. burn off the particulate matter collected), these filters convert a proportion of the nitric oxide emissions in the exhaust stream to NO_2, which is then used for trap regeneration. For diesel vehicles equipped with these filters, the proportion of NOx emitted directly as NO_2 is reported to be around 30%[20], compared to approximately 10% for diesel vehicles not equipped with this technology[21]. Although the NO_2 component is increased, the total NO_X emissions are not increased, and so zero impact on NO_X has been assumed. This remains nonetheless a consideration for meeting local air quality NO_2 limit values.

The measure assumes that, in order to clean up the existing heavy duty fleet (all Euro VI vehicles are assumed to have DPFs fitted, as are those vehicles that have already retrofitted DPFs and some new Euro IV/V vehicles), a scheme is implemented to retrofit DPFs to existing, pre-Euro VI HDVs, similarly to the effect of London’s Low Emission Zone, but nationally.

Capital costs of full flow wall filters are assumed to be £5,500 and operating costs £150[22] per annum.

Uptake rates (as a percentage of existing, pre-Euro VI HDVs) are assumed to be an incremental 5% per annum from 2013 and capped at 60% (i.e. assuming that 40% of the pre-Euro VI fleet already have DPFs) from 2024, which corresponds to retrofitting approximately 22,500 HDVs in 2025 and 3,300 HDVs in 2030.

Hydrogen buses – Measure T4

Hydrogen (H_2) is an energy vector that can be used in road transport either in fuel cell vehicles (FCVs) or directly in adapted internal combustion engines (ICEs). FCVs show substantial point-of-use benefits over other non-H_2 measures because the sole exhaust emission is water vapour and as such their use could have considerable benefits for urban air quality. This measure considers therefore only FCVs.

To consider their associated GHG emissions life-cycle assessment is again crucial due to the various ways in how H_2 can be produced, stored and distributed. H_2 can be produced from many sources – both renewable and non-renewable – and can be in centralised architectures or decentralised to be produced on site on demand, removing issues of distribution. Production of H_2 by electrolysis from nuclear or renewable sources potentially offers the lowest GHG emissions and will likely eventually supersede production using natural gas. Storing H_2 is problematic due to its low volumetric energy density. This property necessitates H_2 distribution and storage that utilise either high compression (e.g. at 700 bar) or liquefaction (temperatures <20K required), both of which may introduce significant life-cycle emission penalties.

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[20] Environmental Industries Commission (EIC) response to the Defra Consultation on Draft Local Air Quality Management Guidance, 3 October 2008.

[21] Welsh Assembly Government Local Air Quality Management Practice Guidance 4: Practice Guidance to Local Authorities on encouraging uptake of retrofit abatement equipment. Draft December 2008. http://wales.gov.uk/docs/desh/consultation /090105airguidance4en.doc?lang=en

[22] Personal communication with Transport for London, 19th May 2008.

Therefore although many pathways exist, on-site electrolysis from renewables likely offers the best win-win scenario (Wang, 2002), and therefore this analysis assumes this pathway will be taken. FCVs are therefore assumed to offer abatement efficiencies of 100% for NOx, PM, VOCs, SO_2, CO_2, CO, CH_4 and N_2O (direct emissions only). It should be noted that H_2 is itself an indirect GHG (global warming potential over 100 year time horizon: 5.8). AQEG (2007) report that a H_2 leakage rate of 1% would result in a (linear) climate impact 0.6% that of the current fossil fuel based system.

A certification scheme may need to be required in order to ensure emission reductions are achieved. Such a scheme does not currently exist.

A barrier to H_2 uptake is the ‘chicken and egg’ problem: without sufficient built infrastructure, vehicle demand will be low and costs high; without sufficient vehicular demand, industry and government are loathe to finance infrastructure. This analysis assumes that the H_2 rollout will be to sectors well-suited to conversion i.e. buses. The uptake of this measure is modelled as the fraction of new buses that will be H_2-powered instead of diesel fuelled. Both measures assume that 10% of new buses in 2020 are hydrogen buses.

Costs for hydrogen buses are currently very high. It is very uncertain what the future costs in 2025 or 2030 will be of the technologies that are both available today and available in 2020, and as such, costs for this measure should be assumed to be upper estimates as technological development and market maturation should reduce costs over time. The costs assumed in this analysis are presented in Table A19.8 and represent extrapolations from Element Energy[23] and NREL (2007), and recent capital cost estimates from TfL[24]. The underlying assumptions of these costs are H_2 fuel consumption of 8 kg/100 km, H_2 costs of \$4/kg, fuel cell renewal costs of \$50,000 and fuel cell lifetime of 20,000 hours. The additional infrastructure costs are excluded.

Table A19.8 Costs assumed for hydrogen FCV buses

	Hydrogen FCV bus	Source
Capital cost (£), additional to conventional diesel bus	£700,000	[24]
Annual maintenance costs (£/year), additional to conventional diesel bus	£1,700	NREL (2007)
Annual fuel savings (£/year)	£900	[23]
Annualised cost of renewing fuel cell (£)	£6,100	[23]

Hybrid buses – Measures T5.1 and T5.2

This technical measure considers the use of hybrid diesel-electric vehicle technology instead of conventional diesel buses. Hybrid buses pair a diesel internal combustion engine with an electric motor that is powered by on-board

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[23] Personal Communication with Element Energy, 12th June 2008

[24] Personal Communication with Transport for London 15th June 2012

batteries which are charged by either regenerative braking or the engine (or both). Hybrids offer reduced emissions 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. Current and BAU uptake of hybrid buses is low, and the NAEI road transport emission projections do not (currently) consider specific technologies such as hybrids; BAU is therefore assumed in the MPMD as zero.

Measure T5.1 considers an uptake of hybrid buses replacing existing pre-Euro VI diesel buses at a rate of 2% of the existing pre-Euro VI fleet per annum starting from 2013. This corresponds to 36% in 2030, about 2,000 buses. In line with recent discussions between AEA and Defra, hybrid buses are assumed to offer a 21% NO_X reduction and 0% impact on PM compared to a Euro IV/V bus.[25] Due to regenerative braking, the measure is assumed to reduce brake wear PM emissions by 30%. Cross media effects are 30% CO_2 reduction and corresponding fuel saving (TfL, 2008). A certification scheme may need to be required in order to ensure emission reductions are achieved. Such a scheme does not currently exist. As this measure would involve the incentivisation of a new vehicle purchase (e.g. through scrappage), the capital costs are those of a conventional diesel bus plus the additional capital cost of a hybrid bus – totalling £320,000. Operating costs are derived from fuel savings (at resource cost), and are approximately £2,700 per annum.

Measure T5.2 considers an uptake of hybrid buses replacing new Euro VI diesel buses at an incremental rate of 5% of the new buses entering the fleet per annum starting from 2013, capped at 80% in 2030, around 2,200 buses. In line with recent discussions between AEA and Defra, hybrid buses compared to new Euro VI buses are not assumed to offer any reductions in NOx emissions. Due to regenerative braking, the measure is assumed to reduce brake wear PM emissions by 30%. Cross media effects are 30% CO_2 reduction and corresponding fuel saving (TfL, 2008). As this measure would involve the incentivisation of choosing a new hybrid vehicle instead of a conventional diesel bus, the capital costs are the additional capital cost of a hybrid bus, i.e. £110,000. Operating costs are derived from fuel savings (at resource cost), and are approximately £2,700 per annum.

Hybrid LGVs – Measure T6

This technical measure considers the use of hybrid vehicle technology to replace existing stock of diesel LGVs. Hybrid LGVs pair a 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 due to decreased use of the combustion engine. Current and BAU uptake of hybrid LGVs is low, and the NAEI road transport emission projections do not (currently) consider specific technologies such as hybrids; BAU is therefore assumed in the MPMD as zero. Hybrid LGVs are however currently commercially available.[26]

This measure assumes an uptake of diesel-electric hybrid LGVs replacing existing pre-Euro 6 diesel LGVs at a rate of 2% of the fleet of existing pre-Euro 6 LGVs per annum starting from 2013. This corresponds to 36% in 2030, about 59,000 LGVs. The impacts on emissions of hybrid LGVs compared to diesel LGVs have been assumed to be as per test results from currently available hybrid LGVs[27]: 41% PM reduction, 1% NOx increase, 71% NMVOC

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[25] Personal communication with AEA and Defra, 26th June 2012.

[26] E.g. www.ashwoods.org

[27] Personal communication with Ashwoods 11th June 2012

reduction, 64% CO reduction and 20% CO_2 reduction. Due to regenerative braking, the measure is assumed to reduce brake wear PM emissions by 30%. The fuel saving is assumed equal to the CO_2 saving.

A certification scheme may need to be required in order to ensure emission reductions are achieved. Such a scheme does not currently exist.

The capital and operational costs are an additional £5,500 and £200/year respectively on top of an average LGV.

Hybrid cars – Measures T7.1 and T7.2

These technical measures consider the use of hybrid vehicle technology to replace existing stock of petrol and diesel cars. Hybrid cars pair an 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 exhaust emissions due to decreased use of the combustion engine. Hybrid cars are widely available commercially.

These measures assume an uptake of electric hybrid cars replacing existing pre-Euro 6 petrol and diesel cars at a rate of 2% per annum above the BAU, resulting in 36% in 2030 (i.e., approximately 237,000 cars in 2030). In 2010 the proportion of vehicles licensed in the UK that were of hybrid electric propulsion was small at 0.3% (DfT, 2011), although the annual growth rate is high.

Hybrid cars are assumed to offer a 56% NOx reduction and 24% NMVOC reduction, 50% CO reduction and 31% CO_2 reduction, as compared to a Euro 5/6 petrol car, calculated from VCA fleet data (VCA, 2011). Compared to Euro 5/6 diesel cars, hybrid cars are assumed to offer an 87% PM reduction, 92% / 82% NOx reduction (compared to Euro 5 and 6 respectively), 20% CO reduction and 17% CO_2 reduction, calculated from VCA fleet data (VCA, 2011). Fuel savings are assumed to be as per CO_2 savings. Due to regenerative braking, the measure is assumed to reduce brake wear PM emissions by 30%.

A certification scheme may need to be required in order to ensure emission reductions are achieved. Such a scheme does not currently exist.

The capital costs uplifted from AEA (2005) of £1900 on top of an average car is offset by negative annual operating costs (compared to an average car) of £190 for petrol cars and £140 for diesel cars due to fuel savings, as calculated using the methodology in Box 2. Note: savings represent the resource cost of fuel, not the pump price.

Box 2 Operational fuel saving calculations

$$Annual\ opex = [\%\ fuel\ saving] \times \frac{[projected\ annual\ \ fuel\ use] \times [forecast\ \ fuel\ resource\ price]}{projected\ vehicle\ numbers}$$

The fuel savings associated with hybrid buses and cars have been calculated according to the following calculation:

Regenerative Braking

Conventional brakes reduce vehicle speeds by using friction to convert kinetic energy to thermal energy. This process involves abrasion of the brake lining and rotors or pad and discs, which produces debris and particles (TRL, 2007). Brake wear emissions occur mainly at sites where rapid deceleration occurs including sharp corners and road junctions.

Hybrid vehicles (HEVs) employ both a conventional (hydraulic or friction) braking system and a regenerative braking system. Whilst travelling at faster speeds hybrids use conventional brakes, at lower speeds the regenerative braking system takes over. The regenerative braking system utilises the vehicles electric motor to provide a negative torque to the driven wheels and converts kinetic energy to electrical energy for recharging the vehicle battery or power supply. Traditional friction-based braking is still required in HEVs even at lower speeds however. When used alone the effect of regenerative braking is dramatically cut at lower speeds so a friction brake is still necessary to bring the vehicle to a halt. Also, most road vehicles only have drive on two wheels and as such regenerative braking only applies to those wheels, so in order to provide controlled braking conventional brakes are required on the other wheels. The rate of regenerative braking is restricted by both the size of the motor-generator and the amount of charge the battery pack can accept.

Electric vehicles (EVs) also utilise the two braking systems with conventional brakes installed as a safety mechanism. For instance, the Mitsubishi iMiEV car has disc brakes on the front wheels and drum brakes on the rear two wheels. For EVs, whose top speed is generally limited to around 50mph, conventional braking is employed to bring the vehicle to a complete stop.

There are several systems responsible for the lower PM emissions of hybrid vehicles compared to their conventional petrol / diesel equivalents: regenerative braking, less transient engine management and regenerative particulate trap control. Few studies have attempted to isolate the impact of each individual component on PM emission abatement.

We have made some general assumptions in order to estimate the percentage of conventional braking that is replaced by regenerative braking in HEVs and EVs. We have assumed that these cars will spend half their time at higher speeds and the rest in ‘stop-start’ mode at lower speeds (for instance, in urban settings) where regenerative braking applies. Given that conventional braking also works to stop the car to a complete halt we have estimated that regenerative braking will apply only 30% of the time and so reduces PM emissions from brake wear by this percentage. However, these assumptions are highly uncertain given the lack of studies focussing on regenerative braking. A report prepared for Defra concluded that whilst regenerative braking does have the potential to have some effect on non-exhaust PM emissions they are not likely to be significant (TRL, 2007).

Retrofitting wet brakes – Measures T8.1, T8.2, T8.3 and T8.4

The vast majority of road vehicles use unenclosed dry friction brakes of either drum or disc design. These braking systems suffer from the wear of the brake shoe or pad, of which a fraction is emitted as PM_{10} and $PM_{2.5}$, and which is not captured and thus released to the atmosphere. Enclosing a disc brake mechanism to prevent PM release is challenging due to the need for ventilation in the brake to avoid over-heating.

Enclosed, wet braking systems designed for harsher off-road environments such as quarrying and mining are already used in these sectors with many years' experience, but have not been significantly applied to the on-road vehicle sector, due to the higher speeds requiring braking. A fully enclosed wet braking system employs an outer casing to protect the brakes against contaminants, and an oil medium to prevent overheating (TRL, 2007). A fully enclosed system eliminates fine PM emissions completely. One company that produces single disc enclosed braking systems has found on-road applications for these brakes, namely commercial 4x4 vehicles, and garbage trucks (heavy duty vehicles).[28] The braking system for rubbish trucks is part way through its development phase. Based on discussions with ABT in 2008, it is assumed that a wet braking system for cars could be produced by 2024 to allow sufficient R&D to come up with a lightweight design, to ensure high speed operation, and to align periods between engine oil and brake oil servicing requirements. Furthermore, city buses are also suitable vehicles that can benefit from such systems due to their stop-start cycles. Additional benefits from wet braking systems that have not been monetised are reduced noise levels from reduced brake squeaking.

As such, a measure of applying a wet braking system for four vehicle types (cars, LGVs, HGVs and buses) has been developed. Uptake rates have been considered to be an incremental 5% per annum of the entire fleet starting in 2018 for HGVs and LGVs and from 2024 for cars to take into account its pre-development status, and for buses an incremental 10% per annum (due to ease to retrofit fleet vehicles) starting from 2020. 2030 uptake rates are therefore 65% for HGVs and LGVs, 35% for cars and 70% for buses. The measure has been considered as a retrofit application, but this technology could also be suitable for new vehicles.

Table A19.9 below lists the assumed brake wear PM abatement efficiency for three vehicle type retrofit applications, and the associated capital and operational costs. Capital costs are estimates for those vehicle types for which development is still in the pipeline, and in all cases incorporate the R&D necessary to bring the product to the market, and the installation[29]. Operational costs consider that due to the heavily reduced wear on the brake pads in a wet braking system compared to a dry brake, the replacement of the brake pads is slowed, but due to the collection of brake dust in the oil, oil servicing is necessary every 10,000-15,000km. It is worth commenting that the cost data have come from a single manufacturer and could not be checked against other sources due to lack of competitors. Due to the prospective nature of such a measure, the potential issue of sufficient supply has been addressed by limiting the uptake to the fleet. Given additional financial support, the measure could potentially be rolled out to a larger number of vehicles.

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[28] E.g. Advanced Braking Technology Ltd. produce the Sealed Integrated Baking System (SIBS). http://www.advancedbraking.com/

[29] Cost rate assumed to be £13.87/hr as for motor mechanics in the Standard Cost Model (updated to 2011£) (BRE, 2005).

Table A19.9 Abatement efficiency and costs (in £2011) of retrofitting three vehicle types with wet sealed brakes.[30]

Vehicle type	Status of development	PM10, PM2.5 abatement efficiency	Lifetime	Capital cost in 2025 (£/vehicle)	Capital cost in 2030 (£/vehicle)	Operating cost (£/vehicle/year) (Note 1)	Fitting cost (£/vehicle)
Heavy goods vehicle	Rubbish trucks in development	100%	2.5 years before refurbishment	£14,600	£11,100	-£2,900	£220
Buses	Not developed	100%	2.5 years before refurbishment	£14,600	£11,100	-£4,700	£220
Light goods vehicle	Commercial 4x4 vehicles already developed. Assume that costs are similar for LGVs	100%	110,000km, i.e. ~5 years pad/rotor replacement interval	£5,800	£4,700	-£290	£220
Passenger cars	Not developed	100%	150,000km, i.e. ~9 years pad/rotor replacement interval	£2,900	£2,900	-£290	£110

Note 1: Operating costs are given as compared to standard drum/disc brakes, i.e. incorporating a positive cost of oil changes, and a negative cost of increasing the service interval between brake pads replacement (e.g. for passenger cars from replacement every 40,000km up to every 150,000km).

Estimated costs to applying the measure to new vehicles have also been obtained – where the costs are additional costs compared to standard braking systems – but are not presented here because the measure has only been applied as a retrofit measure to existing vehicles.

Electric vehicles – Measures T11, T12, T13 and T14

This measure has been considered for petrol and diesel cars, diesel LGVs and buses. A consistent approach has been applied to estimate the potential emission reductions and costs that could be achieved with increased uptake of electric vehicles in place of each of the above vehicle types. A study for BERR and DfT investigated the scope for the transport sector to switch to electric or plug-in hybrid electric vehicles with a particular focus on cars and light duty commercial vehicles[31]. This has formed the basis for the consideration of electric vehicles and has been supplemented by discussions with, and a review of literature from, a number of electric vehicle and battery manufacturers.

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[30] Personal Communication with ABT on 26th May 2009. Costs for passenger cars are estimates that take into account an anticipated AUD$10m R&D cost. Light duty commercial applications are already developed, whilst testing of the heavy duty application is currently underway.

[31] BERR/DfT (2008): Investigation into the scope for the transport sector to switch to electric vehicles and plug-in hybrid vehicles. Report by Arup and Cenex for BERR and DfT, October 2008.

Uptake

The uptake of electric vehicles has been assumed to involve the replacement of existing pre-Euro 6/VI vehicles and the uptake of new electric vehicles in lieu of new Euro 6/VI vehicles.

The BERR/DfT study looked at a range of scenarios including business as usual (70,000 electric vehicles in UK car park by 2020), mid-range (600,000), high-range (1,200,000) and extreme range (2,600,000) each of which is based on differing assumptions on the availability of incentives and charging infrastructure as well as changes in the costs of purchasing an electric vehicle. Note that in 2010, the UK vehicle fleet included 28.4 million registered cars of which only 1,500 were electric cars (DfT, 2011). The NAEI road transport emission projections include a projected BAU assumption on vehicle kilometres that will be driven by electric vehicles in 2030 (AMEC have been asked to keep the figure confidential).

For this study for cars and LGVs we have assumed uptake rates of 15% (8% for LGVs) of the existing pre-Euro 6 fleet would be replaced in 2030 and 8% of the new Euro 6 fleet in 2030 would be new electric vehicles. In combination this yields the following numbers of vehicles in 2030 to be switched to electric (not cumulative): 75,000 petrol cars, 62,000 diesel cars and 38,000 diesel LGVs.

For buses we have assumed a higher uptake rate (double those for cars stated above) reflecting the fact that it may be marginally easier to introduce fleets of electric buses as opposed to cars, although limitations remain on supply, sufficient charging infrastructure and technology development. This results in 1,100 buses being replaced in 2030 (not cumulative).

Approach to estimating emission reductions

Average emission factors (grams per vehicle kilometre, g/vkm) for NOx, PM_{10}, $PM_{2.5}$ and VOCs for each vehicle and fuel type and Euro standard have been derived based on the NAEI emission projections and vehicle kilometre data. CO_2 emissions from petrol and diesel vehicles have been estimated based on the average number of kilometres travelled for each year of interest (vkm divided by vehicle numbers), average vehicle efficiency (calculated from total fuel consumption and vkm data) and Defra greenhouse gas conversion factors for each fuel[32]. To estimate the abatement efficiency of switching to electric vehicles equivalent emission factors have been estimated based on the efficiency of these vehicles (kWh/km) and emissions associated with the generation of electricity (g/kWh).

The long term aim is for electric vehicles to be powered by electricity produced from renewables so that the emissions abatement for all pollutants is essentially 100%. However, at this stage expected capacity from renewables is not considered realistic to accommodate the potential uptake rates and therefore emissions from petrol and diesel vehicles have been compared against equivalent indirect emissions from electric vehicles using electricity from the grid. Emissions from the grid (per kWh) have been estimated for each pollutant and year based on projected NAEI emissions for the power divided by the projected total electricity produced sector (2011 NAEI, UEP 43). This approach takes into account the expected future grid mix from all sources including renewables.

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[32] http://www.defra.gov.uk/environment/business/reporting/conversion-factors.htm

This data has then been converted into g/vkm based on the assumed efficiencies of each electric vehicle type:

- Electric car – 0.145kWh/km in 2025 and 0.13 kWh/km in 2030;
- Electric LGV – 0.30 kWh/km for all years[33];
- Electric bus – 1.0 kWh/km for all years[34].

Abatement efficiency has then been estimated by comparing the emission factors for an electric vehicle with those of an equivalent petrol or diesel vehicle for each pollutant.

Approach to estimating costs

Capital costs have been estimated for each vehicle type based on a review of relevant literature and discussions with key manufacturers. The table below gives an overview of the capital costs assumed for each vehicle type.

Table A19.10 Capital costs assumed for electric vehicles

Vehicle type	Unit capital cost (£)	Assumptions	Source
Car	Average diesel car cost (2008) - £21,900 Average petrol car cost (2008) - £20,200 Battery - £11,100 (2025) / £6,500 (2030)	Battery costs estimated based on 200km range. Assumed to be the only additional cost for an electric car. Costs of recharging infrastructure excluded due to lack of available information.	WhatCar? data WhatCar? data Berr/DfT (2008)
LGV	Vehicle chassis - £37,200 Battery - £14,000 (2025) / £8,200 (2030)	43-64 kWh battery with range of 180 km. Costs of recharging infrastructure excluded due to lack of available information.	Allied Vehicles
Bus (Note 1)	Vehicle chassis - ~£174,400 Battery - £54,700 Recharging infrastructure - ~£27,900	$250,000 150 kWh battery pack with 150 km range ~$2 million per site to support 50 buses	Lithium Force Batteries

Note 1: Costs for electric buses based on single decker fleet with interchangeable batteries – trialled at Beijing Olympics in 2008. Based on a battery swap/replacement scheme rather than a fixed scheme where a bus has to plug in to charge its battery

In order to estimate the operational costs/savings a similar approach to that applied to estimate changes in CO_2 emissions has been applied:

- Average annual kilometres travelled by each petrol or diesel vehicle type of interest has been estimated based on vkm data and numbers of vehicles;

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[33] Personal communication from Allied Vehicles, 12th July 2009 (estimated based on battery size and range).

[34] Personal communication from Lithium Force batteries, 22nd June 2009 (estimated based on battery size and range).

- Average vehicle efficiency (litres of fuel/km) has been calculated from total fuel consumption and vkm data;
- Average annual fuel consumed by each vehicle type estimated based on above calculations – this equates to an operational saving and can be monetised by applying the suitable resource fuel cost from the DfT fuel price projections;
- Electricity consumed by an electric vehicle has been estimated based on the average annual kilometres travelled by an equivalent petrol or diesel vehicle and associated efficiency (kWh/km) – this equates to an operational cost and can be monetised by applying suitable electricity costs. In this case costs of 7 pence (low night time rate) and 16 pence (peak day time rate) per kWh have been assumed (updated from BERR/DfT, 2008) and a split between night time and peak charging of 75:25, respectively (equates to a cost of ~9p/kWh).

This gives average annual savings per vehicle of between £500 and £530 (replacing a diesel car), £410 and £440 (replacing a petrol car), £780 and £790 (replacing a diesel LGV) and £5,500 and £5,600 (replacing a diesel bus) depending on the year of interest.

Transfer of freight from road to rail – Measure N1

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 emission reductions over HGVs of 82% NOx, 92% PM, 86% NMVOC, 90% CO and 92% CO_2 (SRA, 2005). These figures are likely to be optimistic because the comparison was made in 2005 whereas the measure compares freight travelled in 2025/2030. No more recent information was available.

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.

The measure assumes switching a maximum feasible uptake of 10% of HGV vehicle kilometres in both 2025 and 2030.

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.

Eco-driving (existing drivers) – Measure N2.1

Aggressive driving styles result in high fuel consumption and high emissions. Smooth driving by anticipating other traffic and traffic situations and applying a shifting strategy appropriate for modern engines can reduce fuel consumption significantly (TNO et al, 2006).

This non-technical measure assumes that through the use of driving training programmes that target existing drivers (it is assumed that new drivers are taught eco-driving in their driving tests), the benefits of eco-driving can be bestowed upon existing drivers, and their behaviour post-training reinforced using gear shift indicators. A literature review (listed in Table A19.11) yielded average fuel savings of 6.2-10.1%, with an assumed average of these figures of 8% used for this analysis. CO_2, SO_2 and PM emissions from brake wear are assumed to also be reduced by 8%.

Table A19.11 Literature review of fuel savings associated with eco-driving

Source	Low potential fuel saving (%)	High potential fuel saving (%)
CfIT (2007)	5%	10%
SAFED (2007) – Average of case studies	3%	9%
SMMT (2006)	10%	15%
DSA (undated); quoted in CfIT (2007)	8.5%	8.5%
SNRA (1999)	7.9%	13.9%
Johansson *et al*. (2003)	6.3%	8.1%
EEA (2008)	3%	6%
Average	**6.2%**	**10.1%**

Cross media effects are scarcely reported. However, DfT provided details of a study by TNO that found that the use of gear shift indicators on diesel cars promoted early shifting which resulted in a 20% NOx increase in urban driving cycles.

Capital costs are assumed to the cost of the trainer at the training, at £450 per day, with one trainer per two drivers; drivers supply the vehicles to be tested in. Operational cost savings are due to fuel savings, and are calculated as per the methodology in Box 2.

Eco-driving for HGVs and LGVs – Measure N2.3 and N2.4

Safe And Fuel Efficient Driving (SAFED) has demonstrated an average of 10% fuel savings for HGV drivers and 12% from bus and coaches. The SAFED for vans programme in England has shown an average of on-the-day fuel saving of 16%.

In terms of uptake, DfT (2008) found that 23% of fleet operators have had their drivers ‘eco’ trained and that uptake is highest for large fleet operators.

Eco-driving training has been incorporated as a voluntary course in the Driver Certificate of Professional Competence (CPC) for LGV and PCV drivers. The CPC is a compulsory qualification that must be renewed every 5 years. In its first year of operation only 12% of PCV drivers chose to take the eco-driving option. There is insufficient data to evaluate the take-up of eco-driving courses amongst LGV drivers but given the similarities between the two, it can be assumed that a similar proportion of LGV drivers would opt for the course.

Motorway speed limit enforcement – Measure N3

This non-technical measure takes into consideration that a large proportion of vehicles on motorways drive above the speed limit and that emissions of most 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, 2011). From these data, the fraction of cars exceeding the speed limit was found to be 49%, at an average speed of 77.3mph. The fraction of LGVs exceeding the speed limit was found to be 50%, at an average speed of 77.8mph. The impacts on emissions of increased motorway speeds as percentages were taken from table 2 of TNO (2011). It is noted that this measure has an effect on 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. It may be more appropriate to apply this measure to particular motorways or stretches of motorway rather than a blanket approach to the UK as a whole.

CfIT (2007) included speed limit enforcement in a package of recommended measures, with more likely initial compliance rates of 50%, rising to 80%. The compliance rate assumed for this analysis is 90% in 2025 and 2030. Capital costs for this analysis assume comprehensive blanket coverage of SPEC speed cameras (average speed check cameras), scaled up from the manufacturer's equipment quote of £293,000 per 4.5km (Speedcheck, 2005). This figure is scaled up to the entire motorway network of 3,558km (DfT, 2011), 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.

Operational costs comprise safety benefits and fuel savings. A valuation of safety benefits is made (and which is included as a negative operational cost), as a reduction in average speed would lower the number of accidents (DfT, 2005). Safety benefits from accidents avoided are estimated using DfT (2005) to be £33m/year in 2030. Against the high capital cost (to the Exchequer) is a considerable fuel saving (distributed among those who reduce their speed) due to improved fuel efficiency at lower speeds. The operational savings have been calculated from the projected resource cost of fuel (i.e. without tax) and the fractional reduction in fuel consumption from NAEI factors, and it totals £122m/yr in 2030. 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.

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.

Downsizing petrol cars – Measure N4

The most recent NAEI data on the splits of vehicle kilometres and emissions among engine size categories has been used to estimate average emission factors of NO_X, PM_{10} and $PM_{2.5}$ for each engine size category. These data are shown below in Table A19.12. The data show that for petrol cars there is a trend for NO_X and PM, that as engine size increases, the NOx and PM emissions increase. Thus, alongside benefits of decreased fuel consumption and CO_2 emissions, switching to smaller petrol cars (from larger petrol cars) should bring about reductions in NO_X and, to a lesser extent, PM. There is not a similar trend for diesel cars. Oxley et al. (2012) show this to be a 'win-win' measure for both AQ pollutants and GHGs. It is unknown at this stage whether there is an effect on NMVOC emissions.

Table A19.12 NAEI data on splits between petrol and diesel engine sizes, split of vkm and emissions. Average emission factors calculated from emissions divided by vkm.

Vehicle	Engine displacement (cc)	Proportion of vkm	Percentage of NOx Emissions	Percentage of PM Emissions	NOx emission factor (mg/km)	PM_{10} emission factor (mg/km)	$PM_{2.5}$ emission factor (mg/km)
Petrol cars	<1400	41.3%	35.2%	33.1%	51	0.9	0.9
	1400-2000	45.7%	49.7%	36.3%	65	0.9	0.9
	>2000	13.0%	15.0%	30.6%	69	2.8	2.6
Diesel cars	<1400	7.7%	5.2%	5.9%	205	0.7	0.7
	1400-2000	62.0%	63.6%	71.9%	311	1.1	1.1
	>2000	30.3%	31.1%	22.2%	311	0.7	0.7

Apart from 'Proportion of vkm by engine size', which is valid for all years, the figures shown refer to 2030.

A measure has therefore been developed which assumes that the petrol car buyer's purchase can be influenced by information campaigns and / or through grant schemes to choose a petrol powered car with a smaller engine than they otherwise would. Of course, some users need petrol engine cars with larger engines for example towing trailers and other heavier duty uses. It is also noted that one barrier is the lifestyle barrier: an image of status has been formed of larger cars, hence the industry may need to change advertising and provide luxury versions of small cars. Hence the measure assumes that in 2030, cumulatively a maximum of 50% of the petrol car fleet will have chosen to 'downsize' their new vehicle choice (for reference, the petrol car fleet in 2030 is projected to number ~14m, of which ~9m are estimated to be added between 2020 and 2030 inclusive). The measure has been modelled through assuming that 50% of the fleet with petrol engines >2.0*l* switch to cars with petrol engines 1.4-2.0*l*, and that 50% of the fleet with petrol engines 1.4-2.0*l* switch to cars with petrol engines smaller than 1.4*l*.

In light of a lack of information from NAEI on fuel consumption and CO_2 emissions from such petrol cars, data on commensurate fuel savings and CO_2 emission savings have been taken from VCA (2011). Of the Euro 5 petrol cars listed in the VCA database, their average CO_2 emissions (g/km) and fuel consumption (*l*/100km) for each of the three engine size categories has been extracted. These are shown below in Table A19.13. Note: these are not for the weighted fleet average (i.e. they do not take into account the sales-weighting of each car) as no fleet weighted data have been available. The measure results in petrol fuel savings of 2.5bn litres (£1bn) and CO_2 emission savings of 3.5Mt.

Table A19.13 Average fuel consumption and CO_2 emissions for each engine size category (VCA, 2011)

Engine displacement category (cc)	Average fuel consumption (combined cycle) (*l*/100km)	Average CO_2 emissions (g/km)
<1,400	5.7	133
1,400 – 2,000	7.2	167
>2,000	10.6	247

Smaller cars are cheaper to manufacture and produce. ‘OnTheRoad’ list prices for new petrol cars as a function of engine capacity have been obtained (WhatCar?, 2009). Again, these results are not weighted fleet average prices, but they do include ~2000 cars. These prices include delivery, First Registration Fee and one year Road Fund Licence. In order to assess the price differential between engine capacity categories, VAT has been removed and cars with engines greater than 4 litres, and those costing greater than £100,000 have been removed (as have those vehicles fuelled by means other than unleaded petrol). The dataset results in Table A19.14 show the typical savings one could expect from downsizing.

Table A19.14 CAPEX assumptions for downsizing (derived from WhatCar?, 2009[35]) in 2011 prices

Engine displacement category (cc)	Saving if downsize one engine category (£)
<1,400	
1,400 – 2,000	£8,000
>2,000	£13,000

Note 1: Outliers have been removed from the statistical analysis: engines of capacities >4.0litres, cars with list price >£100,000, and one vehicle of null price.

Operational savings result from the fuel savings (and have been calculated as the resource costs of the fuel, i.e. without tax). The lifetime of the measure is assumed to be 12 years for the purposes of annualising the capital costs over the lifetime of the vehicle.

Possible safety implications of driving smaller vehicles has not been assessed due to some research that suggested that “if a uniform downsizing across-the-parc took place, there would be a slight reduction in the total number of casualties in car accidents. However, if it appears that a non-uniform downsizing would occur, further research would be needed to assess the effect on accident casualties” (TRL, 1999).

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[35] Personal Communication with WhatCar?, 18th May 2009.

Road spraying – Measure T15

As listed in Table A19.1, the resuspension of dust is a significant contributor to total PM emissions associated with the road transport sector. Transport for London, has been trialling the use of dust suppressants on parts of the Transport for London Road Network (TLRN) and some borough roads (with borough permission). The dust suppressant that has been trialled is Calcium Magnesium Acetate (CMA), which is a biodegradable liquid. The trials have focussed on spreading CMA across the width of the carriageway at a few priority locations. Interim findings[36] from the first year of the trial demonstrated that the application of CMA achieved up to a 14% decrease in local PM_{10} concentrations. A second phase of the trial is expected to report results in autumn 2012.

Approximate unit capital and operating costs associated with the trials in London have been obtained.[37] For the purposes of applying road spraying as a national measure, it has been assumed that road spraying could as a maximum feasible uptake be deployed at all urban (major and minor) roads in the UK. Road lengths for this network have been taken from DfT (2011). Assuming that one road spraying vehicle can cover 38 lane-kilometres, approximately 3,800 vehicles would be necessary nationwide. Based on TfL's conversion of road gritters for the purpose of spraying, the measure assumes that sprayers cost the same as gritters (without conversion costs), at £110,000 each.[38] TfL noted that the operational costs of between £15 and £20 per lane kilometre was made up of approximately 20% costs from CMA and 80% from staff and machinery.

The effectiveness of this measure on *emission* reductions of PM is unclear. The only method of assessing the effectiveness of the measure has been through measurements of ambient concentration changes. Through lack of data on emissions, the results on ambient concentrations have been adopted as the emission reduction effectiveness (14% for PM_{10}; 3% for $PM_{2.5}$).

A19.4 Summary of measures and costs

Table A19.15 summarises the estimated cost of each abatement technology for the road transport sector. The costs in the summary table are based on the average cost of each abatement technology. The assumptions behind each measure (in section A8.3.2) indicated, where applicable, the range of costs assumed for each measure.

Table A19.16 presents the reduction efficiency of the abatement measures and the associated reduction in emissions.

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[36] http://www.tfl.gov.uk/corporate/projectsandschemes/17246.aspx

[37] Personal communication with TfL, 15th June 2012.

[38] http://present.brighton-hove.gov.uk/Published/C00000535/M00002754/AI00013993/$WinterServiceScrutinyQueriesaboutcosts.doc.pdf

Table A19.15 Summary of beyond BAU abatement measures for the road transport sector (2011 prices).

Measure Reference	Abatement measure	Future uptake of measure (%) (Note 1)		Operating life (years)	Capital Costs (£k, 2011 prices)		Annual operating costs (£k, 2011 prices)		Total annualised costs (£kpa, 2011 prices)	
		2025	**2030**		**2025**	**2030**	**2025**	**2030**	**2025**	**2030**
T3	Retrofit DPF (full wall-flow) to pre-Euro VI existing HDVs	60%	60%	8	£123,720	£18,105	£3,695	£541	£21,693	£3,174
T4	New hydrogen fuel cell buses instead of new diesel buses	6%	10%	12	£130,238	£96,768	£2,193	£1,630	£15,671	£11,644
T5.1	Replace existing pre-Euro VI buses with hybrid buses	26%	36%	12	£1,999,569	£632,024	-£17,206	-£5,271	£189,718	£60,133
T5.2	Incentivise new hybrid buses instead of diesel buses	65%	80%	12	£450,945	£245,761	-£11,288	-£5,963	£35,378	£19,469
T6	Replace existing pre-Euro 6 diesel LGVs with hybrid LGVs	26%	36%	10	£1,118,977	£322,691	£40,690	£11,734	£175,237	£50,535
T7.1	Replace existing pre-Euro 6 petrol cars with hybrid cars	26%	36%	12	£1,175,797	£225,635	-£115,304	-£22,556	£6,372	£794
T7.2	Replace existing pre-Euro 6 diesel cars with hybrid cars	26%	36%	12	£1,122,204	£227,806	-£82,723	-£16,825	£33,407	£6,749
T8.1	Sealed wet brake retrofit (HGVs)	40%	65%	3	£1,874,859	£2,465,105	-£369,364	-£636,006	£426,909	£410,950
T8.2	Sealed wet brake retrofit (LGVs)	40%	65%	5	£8,940,314	£13,196,341	-£430,669	-£787,413	£1,650,367	£2,284,299
T8.3	Sealed wet brake retrofit (cars)	10%	35%	9	£7,405,506	£26,453,708	-£713,470	-£2,548,635	£277,697	£991,982
T8.4	Sealed wet brake retrofit (buses)	20%	70%	3	£284,664	£1,007,771	-£117,511	-£416,014	£3,389	£11,997
T11	Replace existing pre-Euro 6 petrol cars with electric cars and incentivise new electric vehicles	6%	5%	12	£24,764,886	£1,505,724	-£121,016	-£32,798	£2,441,752	£123,020

Measure Reference	Abatement measure	Future uptake of measure (%) (Note 1)		Operating life (years)	Capital Costs (£k, 2011 prices)		Annual operating costs (£k, 2011 prices)		Total annualised costs (£kpa, 2011 prices)	
		2025	**2030**		**2025**	**2030**	**2025**	**2030**	**2025**	**2030**
T12	Replace existing pre-Euro 6 diesel cars with electric cars and incentivise new electric vehicles	6%	6%	12	£25,190,404	£1,522,503	-£134,044	-£33,138	£2,472,758	£124,416
T13	Replace existing pre-Euro 6 diesel LGVs with electric LGVs	9%	12%	12	£15,162,580	£1,517,565	-£76,179	-£29,545	£1,492,905	£127,498
T14	Replace existing pre-Euro VI buses with electric buses	9%	13%	12	£2,351,516	£251,209	-£16,054	-£5,815	£227,290	£20,181
T15	Road spraying	36%	36%	12	£417,685	£417,685	£872,155	£872,155	£915,379	£915,379
N1	Shift road freight to rail freight (note 2)	10%	10%	0	n/a	n/a	n/a	n/a	n/a	n/a
N2.1	Ecodriving (driver training programme to target existing drivers) and application of gear shift indicators	13%	15%	25	£1,299,991	£1,447,348	-£155,996,189	-£188,989,556	-£155,917,313	-£188,901,740
N2.3	Ecodriving for HGVs	34%	40%	25	£8,079	£9,407	-£107,122	-£130,121	-£106,632	-£129,550
N2.4	Ecodriving for LGVs	17%	20%	25	£213,068	£269,893	-£79,226	-£102,431	-£66,299	-£86,055
N3	Motorway speed limit enforcement	49%	49%	8	£850,652	£850,652	-£144,047	-£155,200	-£20,297	-£31,450
N4	Downsizing petrol cars	15%	31%	12	-£17,707,768	-£37,405,352	-£339,303	-£739,133	£1,493,167	-£4,609,987

Note 1: The uptake of measures is defined as within the road transport subsector to which the measure applies. For example, 60% *of* existing pre-Euro VI HDVs.
Note 2: No costs are presented for this measure due to data scarcity.

Table A19.16 Summary of beyond BAU abatement measures efficiency for the road transport sector (Notes 1, 2)

Measure ref.	Abatement measure	Emission reduction efficiency (%) (Note 4)						Reduction in 2025 emissions (kt)						Reduction in 2030 emissions (kt)					
		NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3
T3	Retrofit DPF (full wall-flow) to pre-Euro VI existing HDVs	0%	0%	99%	99%	90%	0%	0	0	0.016	0.017	0.014	0	0	0	0.002	0.002	0.001	0
T4	New hydrogen fuel cell buses instead of new diesel buses (Note 3)	100%	100%	100%	100%	100%	0%	0.009	0	0.000	0.000	0.000	0	0.010	0	0.000	0.000	0.000	0
T5.1	Replace existing pre-Euro VI buses with hybrid buses	21%	30%	0% / 30%	0% / 30%	0%	0%	0.137	0	0.006	0.015	0	0	0.035	0	0.008	0.021	0	0
T5.2	Incentivise new hybrid buses instead of diesel buses	0%	30%	0% / 30%	0% / 30%	0%	0%	0	0	0.001	0.002	0	0	0	0	0.000	0.001	0	0
T6	Replace existing pre-Euro 6 diesel LGVs with hybrid LGVs	-1%	20%	41% / 30%	41% / 30%	71%	0%	-0.007	0	0.038	0.090	0.111	0	-0.001	0	0.054	0.133	0.013	0
T7.1	Replace existing pre-Euro 6 petrol cars with hybrid cars	56%	31%	0% / 30%	0% / 30%	24%	0%	0.208	0	0.046	0.115	0.109	0	0.031	0	0.071	0.177	0.018	0
T7.2	Replace existing pre-Euro 6 diesel cars with hybrid cars	92%	17%	87% / 30%	87% / 30%	0%	0%	4.066	0	0.099	0.200	0	0	0.617	0	0.095	0.234	0	0
T8.1	Sealed wet brake retrofit (HGVs)	0%	0%	0% / 100%	0% / 100%	0%	0%	0	0	0.132	0.330	0	0	0	0	0.224	0.560	0	0
T8.2	Sealed wet brake retrofit (LGVs)	0%	0%	0% / 100%	0% / 100%	0%	0%	0	0	0.177	0.441	0	0	0	0	0.318	0.796	0	0
T8.3	Sealed wet brake retrofit (cars)	0%	0%	0% / 100%	0% / 100%	0%	0%	0	0	0.144	0.359	0	0	0	0	0.529	1.322	0	0
T8.4	Sealed wet brake retrofit (buses)	0%	0%	0% / 100%	0% / 100%	0%	0%	0	0	0.016	0.041	0	0	0	0	0.056	0.141	0	0

Measure ref.	Abatement measure	Emission reduction efficiency (%) (Note 4)						Reduction in 2025 emissions (kt)						Reduction in 2030 emissions (kt)					
		NOx	SO$_2$	PM$_{2.5}$	PM$_{10}$	VOC	NH$_3$	NOx	SO$_2$	PM$_{2.5}$	PM$_{10}$	VOC	NH$_3$	NOx	SO$_2$	PM$_{2.5}$	PM$_{10}$	VOC	NH$_3$
T11	Replace existing pre-Euro 6 petrol cars with electric cars and incentivise new electric vehicles	57%	-1187%	53% / 30%	41% / 30%	99%	0%	0.089	-0.056	0.002	0.005	0.237	0	0.039	-0.007	0.000	0.002	0.063	0
T12	Replace existing pre-Euro 6 diesel cars with electric cars and incentivise new electric vehicles	92%	-1053%	43% / 30%	27% / 30%	98%	0%	1.931	-0.087	0.007	0.011	0.277	0	0.442	-0.009	0.001	0.002	0.070	0
T13	Replace existing pre-Euro 6 diesel LGVs with electric LGVs	80%	-1282%	-38% / 30%	-76% / 30%	98%	0%	0.611	-0.071	0.002	0.006	0.151	0	0.243	-0.014	0.001	0.003	0.075	0
T14	Replace existing pre-Euro VI buses with electric buses	70%	-1128%	1% / 30%	-27% / 30%	-10%	0%	0.082	-0.010	0.000	0.000	0.000	0	0.018	-0.002	0.000	0.000	0.000	0
T15	Road spraying	0%	0%	3%	14%	0%	0%	0	0	0.069	1.116	0	0	0	0	0.069	1.116	0	0
N1	Shift road freight to rail freight (note 2)	82%	0%	92%	92%	86%	0%	0.151	0	0.061	0.086	0.002	0	0.146	0	0.063	0.090	0.002	0
N2.1	Ecodriving (driver training programme to target existing drivers) and application of gear shift indicators	-9%	8%	8%	8%	0%	0%	-2.629	0.003	0.021	0.044	0	0	-3.059	0.003	0.025	0.053	0	0
N2.3	Ecodriving for HGVs	-20%	6%	6%	6%	0%	0%	-0.585	0.002	0.008	0.018	0	0	-0.656	0.003	0.010	0.021	0	0
N2.4	Ecodriving for LGVs	-20%	8%	8%	8%	0%	0%	-1.071	0.001	0.008	0.017	0	0	-1.305	0.002	0.010	0.022	0	0
N3	Motorway speed limit enforcement	19%	5%	2%	1%	0%	0%	1.390	0	0.005	0.005	0	0	1.175	0	0.005	0.004	0	0
N4	Downsizing petrol cars	18%	23%	14%	14%	0%	0%	0.343	0	0.011	0.011	0	0	0.737	0	0.024	0.025	0	0

Note 1: Negative figures indicate penalties, i.e. the measure increases emissions by *x* % or *y* kt.
Note 2: Emission reduction efficiencies presented for electric vehicles are overall reductions taking into account the emissions increase for the power sector.
Note 3: The abatement efficiencies and reductions presented only relate to direct tailpipe emissions. No account is taken of emissions from hydrogen production; the ideal long-term aim should be that hydrogen is produced from renewable sources.
Note 4: Where two figures are shown for PM abatement efficiencies, the first is for exhaust emissions, and the second is for brake wear.

A19.5 References

1. AEA (2005) *Technical and non-technical options for reducing emissions from road transport*. ED48300. Final Report to Defra. AEA Energy & Environment, Didcot.

2. AQEG (2007) *Air Quality and Climate Change: A UK Perspective*. Air Quality Expert Group, Department for Environment, Food and Rural Affairs, London.

3. BERR (2007) Digest of United Kingdom energy statistics 2007.

4. BRE (2005) Measuring Administrative Costs: UK Standard Cost Model Manual Annexes. Better Regulation Executive.

5. CfIT (2007) Transport and Climate Change: Advice to Government from the Commission for Integrated Transport. HMSO, London.

6. Defra (2007) *The Air Quality Strategy for England, Scotland, Wales and Northern Ireland*. Cm 7169 NIA 61/06-07. Department for Environment, Food and Rural Affairs, The Scottish Executive, Welsh Assembly Government and The Department of the Environment for Northern Ireland, London.

7. DfT (2005) Road Casualties Great Britain: 2005. Department for Transport, London. [Online] Available at http://www.dft.gov.uk/pgr/statistics/datatablespublications/accidents/casualtiesgbar/roadcasualtiesgreatbritain2005 [Accessed 21st January 2008]

8. DfT (2008) Road Freight Statistics 2007. [Online] Available from http://www.dft.gov.uk/pgr/statistics/datatablespublications/freight/goodsbyroad/roadfreightstatistics2007

9. DfT (2011) Transport Statistics Great Britain 2010. Available online from http://webarchive.nationalarchives.gov.uk/20110218142807/dft.gov.uk/pgr/statistics/datatablespublications/tsgb/#complete

10. EEA (2008) Success stories within the road transport sector on reducing greenhouse gas emission and producing ancillary benefits. EEA Technical report No 2/2008. European Environment Agency

11. IEA/OECD (2006) Biofuels for Transport. An International Perspective. Available from http://www.iea.org/textbase/speech/2006/ppcbiofuels.pdf

12. IFS (2012) Fuel for thought: the what, why and how of motoring taxation. Available at http://www.ifs.org.uk/publications/6175

13. INFORM (2000) Bus Futures – New Technologies for Cleaner Cities. Inform Inc, New York. Available from http://www.cleanairnet.org/infopool/1411/articles-59981_resource_1.pdf.

14. Johansson, H., Gustafsson, P., Henke, M., and Rosengren, M. (2003) *Impact of EcoDriving on emissions*. Transport and Air Pollution. Proceedings from the 12th Symposium, Avignon.

15. Lapuerta, M., Armas, O. and Rodriguez-Fernandez, J. (2008) Effect of Biodiesel Fuels on Diesel Engine Emissions. *Progress in Energy and Combustion Science*, 34(2008), 198-223.

16. Lipman T and Dellucchi M, Emissions from Nitrous Oxide and Methane from Con ventuional and Alternative Fuel Motor Vehicles, University of California (2002) http://rael.berkeley.edu/sites/default/files/very-old-site/Climatic_Change.pdf

17. MNP (2007) Cost-effectiveness of additional abatement options for cleaner air. Netherlands Environmental Assessment Agency (MNP). Available from http://www.mnp.nl/en/publications/2007/Cost-effectiveness_of_additional_abatement_options_for_cleaner_air.html.

18. NREL (2007) *Fuel Cell Transit Buses: Evaluation Results Update*. Technical Report NREL/TP-560-42249. National Renewable Energy Laboratory, Colorado.

19. Oxley T, Elshkaki A, Kwiatkowski L, Castillo A, Scarbrough T, ApSimon H, 2012, Pollution abatement from road transport: cross-sectoral implications, climate co-benefits and behavioural change, Environmental Science & Policy, 19-20, pp16-32

20. SAFED (2007) *Companies and Drivers Benefit from SAFED for HGVs. A Selection of Case Studies*. Department for Transport. Available from http://www.freightbestpractice.org.uk/download.aspx?pid=119&action=save.

21. SMMT (2006) *Drive Green – Drive Safely. The industry guide to responsible motoring*. The Society of Motor Manufacturers and Traders.

22. SNRA (1999) *Impact of EcoDriving on emissions and fuel consumption, a pre-study*. Publication 1999:165E. Swedish National Road Administration. Available from: http://publikationswebbutik.vv.se/upload/2000/1999_165E_impact_of_ecodriving_on_emissions_and_fuel_consumption.pdf

23. Speedcheck (2005) SPECS – At a Glance. Speed Check [Online] Available from http://www.speedcheck.co.uk/pdf/05_03_11press_sheet.pdf [Accessed 21st January 2008]

24. SRA (2005) Strategic Rail Authority, quoted by Freight on Rail, http://www.freightonrail.org.uk/ConsultationTransport2025.htm

25. TfL (2008) Hybrid Buses: Environmental Benefits. Available from http://www.tfl.gov.uk/corporate/projectsandschemes/environment/2019.aspx

26. TNO, IEEP, and LAT (2006) Review and analysis of the reduction potential and costs of technological and other measures to reduce CO2 emissions from passenger cars. Final Report.

27. TNO (2011) Emission factors for light road traffic at a maximum speed of 130 km/h on motorways. Report number TNO-060-DTM-2011-03219.

28. TRL (1999) The Likely Effects of Downsizing on Casualties in Car Accidents. Report for DfT. Report number PR/SE/123/95 dated March 1999.

29. TRL (2007) A review of abatement measures for non-exhaust particulate matter from road vehicles. Final report for Defra. Report number PPR230.

30. VCA (2011) Car Fuel Consumption and CO2 tools. Vehicle Certification Agency, Department for Transport. [Online, dated August 2011] Available at: http://carfueldata.direct.gov.uk/

31. Wang, M. (2002) *Fuel choices for fuel-cell vehicles: well-to-wheels energy and emission impacts*. Journal of Power Sources: **112**, 1, pp. 307-321.

32. WhatCar? (2009) ‘OnTheRoad Price list of new cars available in the UK in May 2009’.

A20. Contents

A20.Petrol Service Stations

A20.1 Sector profile

There were 8,706 petrol filling stations at the end of 2011, which was less than a quarter of the 1970 total of 37,500 (UKPIA, 2012). In the last ten years, on average more than 400 filling stations close per year due to strong competition between fuel retailers and the increasing costs of compliance with environmental regulations. VOC emissions arise from petrol stations during petrol delivery, spillages, storage tanks and vehicle refuelling. The NAEI projections indicate that vehicle refuelling in petrol service stations is a significant source of VOC emissions (1% in 2025 and 2030) in the UK (VOC emissions from other activities are not significant).

A20.2 Business as usual policies and abatement measures

The Petrol Vapour Recovery Stage I and Stage II Directives (94/63/EC and 2009/126/EC) regulate the storage of petrol and dispensing of petrol in order to reduce VOC emissions by recovering the vapour. The Stage I (PVRI) Directive aims at minimising VOC emissions from the storage of petrol at terminals and service stations, from loading and unloading at terminals, and from unloading at service stations. The Stage II (PVRII) Directive, which came into effect from 1 January 2012, just deals with VOC emissions from refuelling at service stations.

Under the PVRII Directive, all service stations with a petrol throughput of >3,000 m^3 must have PVRII vapour recovery fitted by the end of 2018. In England vapour recovery for refuelling operations at larger petrol stations with an annual petrol throughput of >3,500 m^3 is already a requirement. Petrol vapour capture efficiency must be 85% or more and where the recovered petrol vapour is transferred to a storage tank at the service station, the vapour/petrol ratio must be equal to or greater than 0,95 but less than or equal to 1,05.. From January 2012, any new service station with annual throughput >500 m^3 or any existing service station with annual throughput >500 m^3 that would undergo “major refurbishment” are required to be equipped with stage II vapour recovery (Defra, 2012).

As indicated above, there has been a decline in the number of service stations in the UK. There has also been a decline in sales of petrol over time, as diesel has become increasingly more common. There is some uncertainty regarding the extent to which the historical decline in petrol sales will continue, given the current high differentials between diesel and petrol prices.

A20.3 Beyond business as usual potential abatement measures

20.3.1 Vehicle refuelling

Entec (2009) supported Defra by carrying out the impact assessment for the PVRII Directive. This considered the potential emissions reductions and costs associated with implementing the Commission’s proposals. For this study, the PVRII Directive modelling from the Entec study was used to estimate the proportion of service stations which will be required to have Stage II vapour recovery systems in place out of total number of service stations, which was 72% in 2025 and 78% in 2030[1]. Based on these percentages as BAU uptake rate, we assumed the BBAU uptake rates of Stage II vapour recovery systems to be 28% and 22% for the years 2025 and 2030, respectively. Annualised costs in 2025 and 2030 were also estimated by multiplying the annualised costs to install Stage II vapour recovery systems by the number of stations without without Stage II in place, drawing this information from the Entec (2009) model. An abatement efficiency of 85% was assumed.

A20.4 Summary of measures and costs

Table A20.1 summarises the estimated cost of beyond BAU uptake of stage II petrol vapour recovery. Table A20.2 presents the reduction efficiency and the associated reduction in emissions.

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[1] The latest projection year for the impact assessment was 2027. Therefore, for this analysis the percentage of service stations with Stage II installed in 2030 was assumed to be the same as that for 2027.

Table A20.1 Summary of beyond BAU abatement measures for the Petroleum Service Stations for 2025 and 2030 [1]

Abatement measure	Future uptake of measure (%)		Operating life (years)	Capital Costs (£k, 2011 prices)		Annual operating costs (£k, 2011 prices)		Total annualised costs (£kpa, 2011 prices)	
	2025	2030		2025	2030	2025	2030	2025	2030
Vapour balancing system ("Stage II")	28%	22%	N/A	N/A	N/A	N/A	N/A	44,398	31,287

Note 1: The costs presented here are the average costs for each abatement measure (in case a measure was given a range of costs). Because annualised costs were estimated using a cost model from Entec (2009), no capital and operating costs are presented (i.e. N/A). A discount rate of 3.5% is considered in the analysis.

Table A20.2 Summary of beyond BAU abatement measures efficiency for the Petroleum Service Stations

Abatement measure	Emission reduction efficiency (%)						Reduction in 2025 emissions (kt)						Reduction in 2030 emissions (kt)					
	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3
Vapour balancing system ("Stage II")					85%						2.15						1.58	

A20.5 References

1. Defra (2012). Petrol Vapour Recovery Stage I and Stage II Directives. Website. http://www.defra.gov.uk/industrial-emissions/eu-international/petrol-vapour-recovery-directives/

2. Entec (2009). Impact assessment for European Commission proposal on Stage II petrol vapour recovery, supporting report by Entec UK Limited for Defra, April 2009.

3. United Kingdom Petroleum Industry Association (UKPIA) (2012) UKPIA Statistical review 2012. http://www.ukpia.com/Libraries/Download/Stats_review_2012.sflb.ashx

A21 Contents

A21.VOC Emitting Sectors

A21.1 Introduction

There are a large number of sectors and activities which individually contribute to >1% of total UK VOC emissions (see Table A21.1). Only half of these sources were previously investigated for the MPMD. This indicated that for many of the sources reviewed no measures were identified for inclusion in the MPMD. This is in part because VOC emissions generally arise from numerous dispersed sources, and many of the potential emission reduction measures depend on reformulation of the chemicals used. It is our experience that it is often very difficult to identify and accurately attribute the costs associated with reformulation with VOC emission reductions; as such reformulation may also be driven by other objectives such as improving the product and/or compliance with other legislation such as REACH.

The scoping phase for this phase of work identified that there have been no updates to the BREF documents covering the VOC emitting activities since the initial development of the MPMD. Therefore no additional information is available from this source. The GAINS model, however, indicates many measures (BAU and BBAU) for the reduction of VOC emissions. Using data from GAINS, measures for the sectors and activities identified as high priority for the MPMD have been identified and further screened. The sectors and measures to be considered were discussed and agreed with Defra.

Table A21.1 Sources of VOCs and relative contribution to UK emissions in 2030

Source	Kt per year	% of UK total
2D2_Spirit manufacture - Scotch whisky maturation_Whisky in storage	49.34	7.4%
3D3_Other solvent use_Solvent use	46.00	6.9%
3D3_Industrial adhesives - other_Adhesives and sealants	36.81	5.5%
3D2_Non-aerosol products - automotive products_Carcare products	36.68	5.5%
3D2_Aerosols - cosmetics and toiletries_Aerosols	29.71	4.4%
2B5a_Chemical industry - general_Chemicals and manmade fibres	26.89	4.0%
1A4bi_Domestic combustion_Wood	26.70	4.0%
1B2b_Gas leakage_Natural gas supply	22.81	3.4%
3D2_Aerosols - carcare products_Aerosols	19.45	2.9%
3B1_Surface cleaning - hydrocarbons_Cleaning solvent	16.68	2.5%
3A1_Decorative paint - retail decorative_Retail decorative coatings	16.48	2.5%
1B2aiv_Refineries - process_Process emission	14.81	2.2%

Source	Kt per year	% of UK total
3D2_Non-aerosol products - paint thinner_Population	14.79	2.2%
3D2_Non-aerosol products - household products_Household products	14.42	2.2%
3A2_Industrial coatings - metal and plastic_Metal and plastic coatings	14.33	2.1%
3D2_Non-aerosol products - cosmetics and toiletries_Cosmetics and toiletries	13.90	2.1%
1B2ai_Crude oil loading from onshore facilities_Crude oil	13.73	2.0%
1B2ai_Crude oil loading from offshore facilities_Crude oil	11.06	1.6%
3A1_Decorative paint - trade decorative_Trade decorative coatings	10.62	1.6%
2D2_Other food - animal feed manufacture_Animal feeds	10.35	1.5%
1A2fii_Industrial off-road mobile machinery_Gas oil	10.32	1.5%
3D2_Aerosols - household products_Aerosols	10.28	1.5%
1A2fii_Industrial off-road mobile machinery_Petrol	8.92	1.3%
1B2av_Petrol stations - vehicle refuelling_Petrol (unleaded)	8.48	1.3%
6A_Landfill_Non-fuel combustion	8.26	1.2%
1A4bi_Domestic combustion_Coal	8.17	1.2%
3D3_Road dressings_Non fuel bitumen use	8.03	1.2%
1B2c_Oil Production - gas flaring_Non-fuel combustion	6.56	1.0%
1B2c_Oil Production - gas venting_Non-fuel combustion	5.90	0.9%
1B2aiv_Refineries - drainage_Process emission	5.24	0.8%
2D2_Other food - margarine and other solid fats_Fats	5.08	0.8%
3A2_Industrial coatings - wood_Wood coatings	5.00	0.7%
1B2aiv_Refineries - tankage_Process emission	4.61	0.7%
3B2_Dry cleaning_Solvent use	4.43	0.7%
6Ce_Small-scale waste burning_Waste	4.14	0.6%
3D2_Agriculture - agrochemicals use_Agrochemical active ingredient	3.86	0.6%
3B1_Surface cleaning - oxygenated solvents_Cleaning solvent	3.57	0.5%
3C_Coating manufacture - other coatings_Solvent used in coating	3.45	0.5%
1A4ci_Agriculture - stationary combustion_Straw	3.37	0.5%

A21.2 Industrial adhesives

21.2.1 Sector Profile

Table A21.2 presents the emissions of VOCs from industrial adhesives developed by AEA, based on DECC's UEP43 forecasts and the 2009 National Atmospheric Emission Inventory (NAEI).

Table A21.2 Emissions of VOCs from industrial adhesives and relative contribution to UK emissions for 2030

Source Name	Activity Name	Emissions (kt)	% of total UK VOC emissions
1A3dii_Industrial adhesives - other_Adhesives and sealants	Adhesives and sealants	36.81	5%

The industrial adhesives sector is diverse and includes the application of adhesives by spray, roller, brush and other techniques to a variety of substrates. It is used in a wide range of industries, including the manufacture of construction products; footwear; furniture and other wood items; lamination; flexible packaging; and vehicle manufacture (Entec, 2003).

There is a variety of different types of adhesives. With the exception of pressure-sensitive adhesives, all types undergo a transformation that is the basis for their function; such transformation is induced through imposition of time, heat or radiation (either passively or actively). Types of adhesives include (Kirk Othmer, 2003):

- Solutions or dispersions of solids in a solvent which dry to leave a film of adhesive. These include:
  - Solvent-based adhesives (this is the main category that includes VOCs);
  - Water-based adhesives (which may include a small proportion of VOCs, of the order of a few percent);
- Reactive adhesives which act by forming chemical bonds by cross-linking or polymerisation;
- Solid adhesives (e.g. hot-melt adhesives) which are heated during application and become functional upon cooling;
- Pressure-sensitive adhesives which remain in place (including the solvent) on the substrate throughout their life.

Emissions of VOCs occur when solvent-based coatings are used, mainly as a result of the drying process, though emissions may also occur during handling, loading and mixing operations, as well as cleaning and storage (Defra *et al*, 2004).

The UK adhesives market and associated solvent consumption in 1992 is set out in Table A21.3 (no more recent data were available within the timescales for this project). As indicated, in 1992, 17% of adhesives were solvent-based with pressure-sensitive adhesive tapes and labels, followed by construction, the largest users of these types of adhesives.

Table A21.3 UK adhesives market in 1992

Sector	Total use of adhesive (kt)	Volume share of market (%)	Solvent-based adhesive use (kt)	Solvent-based as % of total sector use	Share of total solvent-based adhesive
Packaging	123	34	0.6	<1	1
Construction	54	15	14	25	22
PSA Tapes & Labels	51	14	28	54	46
Wood Working/Furniture	23	7	2.6	11	4
Book Binding	9	3	0	0	0
Transport	8.9	2	1.7	19	3
Lamination	8.6	2	1.9	22	3
Disposables	7.1	2	0	0	0
Consumer	4.8	1	1.2	25	2
Footwear	4.7	1	3.3	70	5
Other	32	9	3.8	12	6
Sealants	31	9	4.1	13	7
Totals	**357**	**100**	**60.2**	**17**	**100**

Source: Entec (1999). Figures have been rounded

Total use of adhesives in the UK at present is similar to the historical amount included above: net supply in the UK in 2006 was 334kt[1] and this has remained relatively constant since 2003 (National Statistics, 2007).

21.2.2 Business as usual policies and abatement measures

Undoubtedly, the use of adhesives and relative quantities of solvent-based adhesives will have changed since 1992, with a move to reactive and water-based adhesives. There has been a significant reduction in VOC emissions as a result of these changes and from increased use of emissions abatement in industrial adhesive coating activities.

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[1] This includes prepared glues and other prepared adhesives; products suitable for use as glues or adhesives excluding casein glues, glues of animal origin, glues based on starches or modified starches.

The main drivers for the reductions in VOC emissions from this sector include:

- The Solvent Emissions Directive (1999/13/EC).
- Previous requirements in the UK under the Local Air Pollution Control regime.
- Other initiatives such as the industry Coatings Care programme.

The Solvent Emissions Directive has been the main legislative driver for reducing VOC emissions from this sector over recent years. The restrictions imposed by these policies have led to a number of abatement measures already being applied to the sector, as presented in Table A21.4. This information is based on the GAINS model which includes information on the baseline uptake.

Table A21.4 BAU abatement measures in the industrial adhesives sector

Process	Pollutant	Current measures	BAU uptake in 2030
Substitution of solvent-based adhesives with alternatives	VOCs	• Substitution with hot melts or UV cross-linking acrylates or electron beam curing systems (solids content 100%). • Substitution with emulsions, water-based dispersion paints.	• 40% • 53.5%
Abatement of emissions through thermal oxidation (incineration) or carbon adsorption	VOCs	• Incineration of VOCs in the use of high performance solvent based adhesives. • Adsorption and incineration of VOCs in the use of high performance solvent based adhesives. • Adsorption and incineration of VOCs in the use of traditional solvent based adhesives.	• 36.5% • 33.8% • 33.8%

21.2.3 Beyond business as usual potential abatement measures

As indicated above, significant abatement is already achieved as a result of the Solvent Emissions Directive and under UK legislative requirements. Further abatement of emissions could potentially be achieved through additional uptake of the same techniques indicated in the section above, including:

- Substitution of solvent-based adhesives with alternatives, including solid or reactive adhesives which do not include solvents released upon curing, or with water-based adhesives which generally contain much lower concentrations of VOCs (if any). This option will not be suitable for all applications (for example, solvent-free adhesives may not be suitable for some uses where high adhesion strength is not required).
- Abatement of emissions through thermal oxidation or carbon adsorption. These are already applied in certain sectors and could potentially be taken up further. However, there are technical limitations on

the extent to which this is possible, such as the application process (e.g. where applied in a variable manner according to specific needs such as in shipbuilding[2]) or the VOC content of the releases (e.g. low VOC concentrations may not lend themselves to abatement).

The GAINS model includes information on the baseline uptake of some of the above emissions reduction techniques and the associated emission reductions and costs (see Table A21.5). In the absence of detailed information on the potential for additional abatement based on UK-specific data, information from the GAINS model has been used.

Table A21.5 BBAU abatement measures in the industrial adhesives sector (GAINS)

Measure	Removal efficiency	€/ t VOC
Substitution with hot melts or UV cross-linking acrylates or electron beam curing systems (solids content 100%).	100%	-104.8
Substitution with emulsions, water-based dispersion paints.	98%	643.4
Incineration of VOCs	76%	221.0

The emissions projections in the GAINS model are significantly different from the UK emissions projections for this sector. It is understood that this reflects a more optimistic approach to estimating uptake of end-of-pipe abatement and substitution of high-solvent adhesives than is assumed in the UK projections.

As a conservative estimate, it has been assumed that additional emissions reductions could be achieved based on the level that could be achieved as estimated in the GAINS model (i.e. comparison of the GAINS baseline and the maximum feasible reduction estimates). The emission reduction has been compared to the projected UK emissions in 2030, leading to a lower reduction in emissions as a percentage of the baseline as compared to the GAINS estimates. Based on the GAINS model, the additional emissions reductions that could be achieved are as follows:

- Additional uptake of water-based adhesives for 1.5% of adhesive use in 2030 where no other abatement is currently otherwise foreseen. This could reduce emissions by 0.5kt at a cost of £292,000 per year (around £539/t).

- Additional uptake of reactive/solid adhesives for 1.5% of adhesive use in 2030 where no other abatement is currently otherwise foreseen. This could reduce emissions by 0.5kt with a saving of £49,000 per year (around -£90/t).

- Additional uptake of control with incineration for 30% of activities where no control is otherwise foreseen in 2030. This could reduce emissions by 7.8kt at a cost of £1.5m per year (around £185/t).

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[2] Where it will sometimes be impractical to capture and abate VOC emissions.

These emissions reductions are based on our own judgement following a review of previous studies, the UK emissions projections and the projections/assumptions within the GAINS model. They should be viewed as indicative only.

21.2.4 Summary of measures and costs

Table A21.6 summarises the estimated cost of each abatement technology for the adhesives sector. The costs are summarised above and are per tonne VOC abated, as no data on capital and operating costs was available.

Table A21.7 presents the reduction efficiency of the abatement measures and the associated reduction in emissions.

Table A21.6 Summary of beyond BAU abatement measures for the Industrial adhesives sector

Abatement measure	Future uptake of measure (%)		Operating life (years)	Capital Costs (£k, 2011 prices)		Annual operating costs (£k, 2011 prices)		Total annualised costs (£kpa, 2011 prices)	
	2025	2030		2025	2030	2025	2030	2025	2030
Additional substitution of traditional solvent based adhesives with water-based dispersion paints (no baseline abatement)	1.5%	1.5%	-	-	-	-	-	-45	-49
Additional substitution of traditional solvent adhesives with reactive/solid adhesives (no baseline abatement)	1.5%	1.5%	-	-	-	-	-	273	292
Additional control of high performance solvent based adhesives with incineration (no baseline abatement)	29.7%	29.7%	-	-	-	-	-	73	78

Note 1: A discount rate of 3.5% is considered in the analysis.

Table A21.7 Summary of beyond BAU abatement measures efficiency for the Industrial adhesives sector

Abatement measure	Emission reduction efficiency (%)	Reduction in 2025 emissions (kt)	Reduction in 2030 emissions (kt)
	VOC	VOC	VOC
Additional substitution of traditional solvent based adhesives with water-based dispersion paints (no baseline abatement)	100%	0.52	0.52
Substitution of traditional solvent adhesives with reactive/solid adhesives (no baseline abatement)	98%	0.51	0.51
Additional control of high performance solvent based adhesives with incineration (no baseline abatement)	76%	7.77	8.31

21.2.5 References

1. AEA (March 2012) “2012 Air Quality Emission Projections” - A report of the National Atmospheric Emissions Inventory AEA Group.

2. DECC (November 2008) “Updated energy and carbon emission projections” - http://www.berr.gov.uk/files/file48514.pdf

3. Entec (2003): Revision of cost curve for VOCs, A report for Defra, March 2003.

4. IIASA (July 2008) “NEC Scenario Analysis Report Nr. 6 - National Emission Ceilings for 2030 based on the 2008 Climate & Energy Package”. http://www.iiasa.ac.at/rains/reports/NEC6-final110708.pdf

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

A21.3 Domestic use of solvents

21.3.1 Sector Profile

Table A21.8 presents the emissions of VOCs from the use of domestic products developed by AEA, based on DECC’s UEP43 forecasts and the 2009 National Atmospheric Emissions Inventory (NAEI). These do not include the domestic use of paint, nor paint thinners (these are treated within the report section on the decorative paints sector).

Table A21.8 Emissions of VOCs from the domestic products sector and relative contribution to UK emissions for 2030

Source Name	Activity Name	Emissions (kt)	% of total UK VOC emissions
Non-aerosol products - automotive products	Non-aerosol products - automotive products_Carcare products	36.67	5%
Non-aerosol products - cosmetics and toiletries	Non-aerosol products - cosmetics and toiletries_Cosmetics and toiletries	13.90	2%
Non-aerosol products - household products	Non-aerosol products - household products_Household products	14.42	2%
Aerosols - carcare products	Aerosols - carcare products_Aerosols	19.45	3%
Aerosols - cosmetics and toiletries	Aerosols - cosmetics and toiletries_Aerosols	29.71	4%
Aerosols - household products	Aerosols - household products_Aerosols	10.28	1%

21.3.2 Business as usual policies and abatement measures

There are currently no policies or regulations limiting the content of VOC in domestic products. No identified policy or regulation changes have been identified that are expected to have an effect on emissions in 2030.

21.3.3 Beyond business as usual potential abatement measures

In domestic products, VOCs can have different functions, such as a propellant in aerosols or as a solvent in fragrances (amongst others). In some cases VOCs can be used as propellant and solvent at the same time (which will affect the techniques available to reduce emissions).

A study by BiPRO (2002) identifies three major alternatives to the use of VOCs as a propellant in aerosols, such as use of systems with pump mechanism, use of systems with compressed gas, or use of another application method altogether. The BiPRO report also indicates alternatives to the use of VOCs as solvents, preservatives, or fragrances in cosmetics. These alternatives include a change in the application method (use of powder, tablets, etc.) or reformulation/new formulations, using non-VOC or low-VOC agents. The same applies to cleaning products, where VOCs can be used as a solvent, fragrance or disinfectant.

Although the study by BiPRO does describe abatement techniques, their assessment is undertaken only on a qualitative basis and the report does not provide information on the practicalities of implementation and the extent to which any one technique is likely to be used in the future. Their study therefore sets out three scenarios describing the reduction potential associated with measures identified:

- Stage I: achievable (advantages and disadvantages need to be assessed in detail);
- Stage II: possibly achievable (high efforts and disadvantages in some areas might occur);
- Stage III: very difficult to achieve (significant efforts and disadvantages have to be expected).

The GAINS model estimates the cost of reformulation of products for the three stages developed by BiPRO (see Table A21.9).

Table A21.9 BBAU abatement measures in the domestic products sector (GAINS database)

Measure	Removal efficiency	€/ t VOC
Stage 1 reformulation	10	4,679
Stage 2 reformulation	28	5,776
Stage 3 reformulation	60	11,551

This information has been used here to develop the measures for the MPMD. The additional emissions reductions that could be potentially achieved are as follows:

- Additional uptake of control with Stage 1 reformulation for 25% of emissions not controlled in 2030 could reduce emissions by 3kt at a cost of £12m per year (around £4,000/t).
- Additional uptake of control with Stage 2 reformulation for 50% of emissions controlled with Stage 1 reformulation in 2030 could reduce emissions by 17kt at a cost of £84m (around £5,000/t).
- Additional uptake of control with Stage 3 reformulation for 20% of emissions not controlled in 2030 could reduce emissions by 15kt at a cost of £144m (around £9,500/t)

21.3.4 Summary of measures and costs

Table A21.10 summarises the estimated cost of each abatement technology for the adhesives sector. The costs are summarised above and are per tonne VOC abated, as no data on capital and operating costs was available.

Table A21.11 presents the reduction efficiency of the abatement measures and the associated reduction in emissions.

Table A21.10 Summary of beyond BAU abatement measures for the Domestic products sector

Abatement measure	Future uptake of measure (%)		Operating life (years)	Capital Costs (£k, 2011 prices)		Annual operating costs (£k, 2011 prices)		Total annualised costs (£kpa, 2011 prices)	
	2025	2030		2025	2030	2025	2030	2025	2030
Stage 1 reformulation	25%	25%	-	-	-	-	-	11,844	12,195
Stage 2 reformulation	50%	50%	-	-	-	-	-	81,875	84,302
Stage 3 reformulation	20%	20%	-	-	-	-	-	140,358	144,517

Note 1: A discount rate of 3.5% is considered in the analysis.

Table A21.11 Summary of beyond BAU abatement measures efficiency for the Domestic products sector

Abatement measure	Emission reduction efficiency (%)	Reduction in 2025 emissions (kt)	Reduction in 2030 emissions (kt)
	VOC	VOC	VOC
Stage I reformulation	10	3.02	3.11
Stage II reformulation	28	16.92	17.42
Stage III reformulation	60	14.50	14.93

21.3.5 References

1. BiPRO (2002): Screening study to identify reductions in VOC emissions due to the restrictions in the VOC content of products. A report for the European Commission, February 2002.

2. Entec (2003): Revision of cost curve for VOCs, A report for Defra, March 2003.

A21.4 Organic chemicals

21.4.1 Sector Profile

Table A21.12 presents the emissions for organic chemicals developed by AEA, based on DECC's UEP 43 forecasts (with 2009 baseline NAEI emissions).

Table A21.12 Emissions of VOCs from organic chemicals and relative contribution to UK emissions for 2030

Source Name	Activity Name	Emissions (kt)	% of total UK VOC emissions
Chemical industry - general	Chemicals and manmade fibres	26.89	4%

There are two main parts to this sector, the large volume organic chemicals sector and the speciality or fine organic chemicals sector. For both of these, volatile organic compounds (VOC) are the main pollutant released to air.

Operators in the large volume organic chemicals (LVOC) sector are large chemical companies or petroleum companies. Many of the operating plants are relatively old, but have been periodically renewed by expansion. Most LVOC processes are based on petroleum feed-stocks such as naphtha, gas oil, or associated gas in which benzene, toluene and xylene aromatics are converted in downstream processes to other organic chemicals. In the UK there are typically between one and five plants operating for each LVOC process. The products are usually commodity intermediates that are supplied to other chemical plants or companies. Basic LVOCs are sold on chemical specifications rather than (usually) brand name or performance in use. As a result, competition is focused heavily on price[3].

The speciality chemicals sector is composed of around 350 companies in the UK; major product groupings include: intermediate chemicals for the pharmaceutical and agrochemical industries; pigment and dyestuff intermediates; fluorescent brightening agents; biocides; plastic additives; and flame retardants. The majority of companies

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[3] Environment Agency (2002) Guidance for the Large Volume Organic Chemicals Sector. Integrated Pollution Prevention and Control

manufacture or wholesale chemicals as their primary business activity, but rubber and plastic product manufacture is also important[4].

21.4.2 Business as usual policies and abatement measures

The key BAU policies applying to the organic chemicals sector, as concerns VOC emissions, are the IPPC Directive and the Solvent Emission Directive requirements (both of which are now part of the Industrial Emissions Directive).

A number of abatement techniques are available to comply with this legislation, targeting both point-source emissions (from the numerous permitted process release points on large plants) and fugitive emissions (from the numerous storage tanks, flanges, pumps and valves with seals, tanker connections, sample points, and various plant items which are present on large plants).

The GAINS model contains a number of measures for VOC abatement in the organic chemicals sector, shown in Table A21.13. As agreed with Defra, three of these measures have been selected for development in the MPMD on a basis of abatement efficiency and cost effectiveness.

Table A21.13 Measures in GAINS for organic chemicals

Measures	% of total activity controlled in 2030	Euro / t_VOC	Removal efficiency (%)	Reason for selection
Emissions of NMVOC-Organic chemical industry, storage-Internal floating covers or secondary seals-[kt VOC]	0	3116.6	6.3	Not selected
Emissions of NMVOC-Organic chemical industry, storage-Internal floating covers/sec.seals,vapour recovery (single stage)-[kt VOC]	69	6522.8	94.7	Not selected – already BAU
Emissions of NMVOC-Organic chemical industry, storage-Internal floating covers/sec.seals,vapour recovery (double stage)-[kt VOC]	0	7290.7	98.4	Highest abatement efficiency
Emissions of NMVOC-Organic chemical industry, storage-Vapour recovery unit (single stage)-[kt VOC]	0	6128.9	88.4	Not selected
Emissions of NMVOC-Organic chemical industry, storage-Vapour recovery unit (double stage)-[kt VOC]	0	6846.4	92.1	Highest abatement efficiency
Emissions of NMVOC-Organic chemical industry - downstream units-Leak detection and repair program, stage I-[kt VOC]	100	-101.0	34.0	Most cost-effective option

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[4] Environment Agency (2003) Guidance for the Speciality Organic Chemicals Sector. Integrated Pollution Prevention and Control

Measures	% of total activity controlled in 2030	Euro / t_VOC	Removal efficiency (%)	Reason for selection
Emissions of NMVOC-Organic chemical industry - downstream units-Leak detection and repair program, stage II-[kt VOC]	0	-101.3	36.0	(further investigation require)
Emissions of NMVOC-Organic chemical industry - downstream units-Leak detection and repair program, stage III-[kt VOC]	0	-92.5	36.0	

21.4.3 Beyond business as usual potential abatement measures

Three measures have been taken forward based on the information available in GAINS. They include:

- Further developing and extending site Leak Detection And Repair (LDAR) programmes according to industry best practice to reduce fugitive emissions, including, when possible, smart LDAR;
- Adding a second vapour recovery (adsorption) stage to processes where only a primary stage exists;
- Replacing the oldest, largest VOC storage tanks with state-of-the-art floating roof types with secondary seals.

The assumptions on further uptake of these measures is based on previous cost curve work by Entec (Entec, 2003).

21.4.4 Summary of measures and costs

Table A21.14 summarises the estimated cost of each abatement technology for the organic chemicals sector. The costs are summarised above and are per tonne VOC abated, as no data on capital and operating costs was available.

Table A21.15 presents the reduction efficiency of the abatement measures and the associated reduction in emissions.

Table A21.14 Summary of beyond BAU abatement measures for the organic chemicals sector

Abatement measure	Future uptake of measure (%)		Operating life (years)	Capital Costs (£k, 2011 prices)		Annual operating costs (£k, 2011 prices)		Total annualised costs (£kpa, 2011 prices)	
	2025	2030		2025	2030	2025	2030	2025	2030
Internal floating covers/sec.seals, vapour recovery (double stage)	10%	10%	-	-	-	-	-	14,471	16,154
Vapour recovery unit (double stage)	5%	5%	-	-	-	-	-	6,359	7,099
LDAR Stage 2	20%	20%	-	-	-	-	-	-147	-164
LDAR Stage 3	20%	20%	-	-	-	-	-	-134	-150
LDAR Stage 4	20%	20%	-	-	-	-	-	-74	-83

Note 1: A discount rate of 3.5% is considered in the analysis.

Table A21.15 Summary of beyond BAU abatement measures efficiency for the organic chemicals sector

Abatement measure	Emission reduction efficiency (%)	Reduction in 2025 emissions (kt)	Reduction in 2030 emissions (kt)
	VOC	VOC	VOC
Internal floating covers/sec.seals, vapour recovery (double stage)	98%	2.37	2.64
Vapour recovery unit (double stage)	92%	1.11	1.24
LDAR Stage 2	34%	1.73	1.94
LDAR Stage 3	36%	1.73	1.94
LDAR Stage 4	36%	2.26	2.53

21.4.5 References

1. Entec (2003): Revision of Cost Curve for VOCs, A report for Defra, March 2003
2. GAINS model

A21.5 Dry cleaning

21.5.1 Sector Profile

Table A21.16 presents the projected emissions for the dry cleaning sector developed by AEA, based on DECC's UEP 43 forecasts (with 2009 baseline NAEI emissions).

Table A21.16 Emissions of VOCs from dry cleaning and relative contribution to UK emissions for 2030

Source Name	Activity Name	Emissions (kt)	% of total UK VOC emissions
Dry cleaning	Solvent use	4.43	1%

21.5.2 Business as usual policies and abatement measures

The key BAU policy applying to the dry cleaning sector, as concerns VOC emissions, is the Solvent Emissions Directive (now part of the Industrial Emissions Directive).

The GAINS model contains a number of measures for VOC abatement in the dry cleaning sector, shown in Table A21.17. Three of the measures have been selected for further research on the basis of abatement efficiency and cost effectiveness.

Table A21.17 Measures in GAINS for the dry cleaning sector

Measures	% of total activity controlled in 2030	Euro / t_VOC	Removal efficiency (%)	Reason for selection
Textiles (clothing)-Dry cleaning-Activated carbon adsorption	0	-175.35	70.0	Most cost effective

Measures	% of total activity controlled in 2030	Euro / t_VOC	Removal efficiency (%)	Reason for selection
Textiles (clothing)-Dry cleaning-Conventional closed circuit machine	100	-256.69	89.0	Not selected – already BAU
Textiles (clothing)-Dry cleaning-Combination of the above options	0	141.00	91.0	Not selected
Textiles (clothing)-Dry cleaning-Hydrocarbon machine	0	312.16	95.0	Not selected
Textiles (clothing)-Dry cleaning-New generation closed circuit machine	0	-87.33	95.0	Not selected
Textiles (clothing)-Dry cleaning-Water cleaning	0	-165.41	100.0	Highest abatement efficiency
Textiles (clothing)-Dry cleaning (new installations)-Activated carbon adsorption	0	19,660.52	18.2	Not selected
Textiles (clothing)-Dry cleaning (new installations)-Hydrocarbon machine	0	14,592.28	54.5	Not selected
Textiles (clothing)-Dry cleaning (new installations)-New generation closed circuit machine	90	8,267.08	54.5	Not selected
Textiles (clothing)-Dry cleaning (new installations)-Water cleaning	10	573.12	100.0	Highest abatement efficiency

According to Commission developed guidance for dry cleaning (Commission, 2009), ‘closed machines, equipped with a condenser with refrigerated cooling coils and an activated carbon filter to recover the solvent, have lower consumptions of Perc and emissions are typically less than 10 g/kg’. It also lists a number of VOC-free dry cleaning options, including wet cleaning and liquid CO_2, although it states that none of these have quite the same stain-removing power of the most commonly used solvent, perchloroethylene (Perc) and can be more expensive (Commission, 2009). It also states that ‘from an economic point of view, at least 35 % of garments are suitable for wet cleaning.’

21.5.3 Beyond business as usual potential abatement measures

The GAINS model indicates that in 2030, 100% of installations not characterised as ‘new’ are expected to have closed circuit machines in place. New installations are considered to be fitted with either new generation closed circuit machinery or wet cleaning. The additional emissions reductions that could be potentially achieved are as follows:

- Additional implementation of wet cleaning where use of new generation closed circuit machinery is already foreseen in 2030 for 35% of activities could reduce emissions by 1.5kt at a cost of £744,000 per year (around £480/t).

21.5.4 Summary of measures and costs

Table A21.18 summarises the estimated cost of each abatement technology for the dry cleaning sector. The costs are summarised above and are per tonne VOC abated, as no data on capital and operating costs was available.

Table A21.19 presents the reduction efficiency of the abatement measures and the associated reduction in emissions.

Table A21.18 Summary of beyond BAU abatement measures for the dry cleaning sector

Abatement measure	Future uptake of measure (%)		Operating life (years)	Capital Costs (£k, 2011 prices)		Annual operating costs (£k, 2011 prices)		Total annualised costs (£kpa, 2011 prices)	
	2025	2030		2025	2030	2025	2030	2025	2030
Water cleaning at new dry cleaning installations (baseline is closed circuit machinery)	35%	35%	-	-	-	-	-	744	744

Note 1: A discount rate of 3.5% is considered in the analysis.

Table A21.19 Summary of beyond BAU abatement measures efficiency for the dry cleaning sector

Abatement measure	Emission reduction efficiency (%)	Reduction in 2025 emissions (kt)	Reduction in 2320 emissions (kt)
	VOC	VOC	VOC
Water cleaning at new dry cleaning installations (baseline is closed circuit machinery)	100	1.55	1.55

21.5.5 References

1. Commission (2009) Guidance on VOC Substitution and Reduction for Activities Covered by the VOC Solvents Emissions Directive (Directive 1999/13/EC) Guidance 11: Dry cleaning, produced by AEA Okopol and BiPRO. Available online at http://circa.europa.eu/Public/irc/env/voc/library?l=/guidance_documents/final_versions&vm=detailed&sb=Title [Accessed on 19/03/12]

A21.6 Agrochemicals

21.6.1 Sector Profile

Table A21.16 presents the emissions for the agrochemicals sector developed by AEA, based on DECC's UEP 43 forecasts (with 2009 baseline NAEI emissions).

Table A21.20 Emissions of VOCs from agrochemicals and relative contribution to UK emissions for 2030

Source Name	Activity Name	Emissions (kt)	% of total UK VOC emissions
Agriculture - agrochemicals use	Agrochemicals active ingredient	3.86	1%

21.6.2 Business as usual policies and abatement measures

The key BAU policy applying to the agrochemicals sector, as concerns VOC emissions, is the Solvent Emissions Directive (now part of the Industrial Emissions Directive).

The GAINS model contains some measures for VOC abatement in the agrochemicals sector, shown in Table A21.21.

Table A21.21 Measures in GAINS, agrochemicals sector

Measures	% of total activity controlled in 2030	Euro/t_VOC	Removal efficiency (%)
Emissions of NMVOC-Other industrial use of solvents-Agrochemicals - new products-[kt VOC]	0	17.6	20.0

Measures	% of total activity controlled in 2030	Euro/t_VOC	Removal efficiency (%)
Emissions of NMVOC-Other industrial use of solvents-Primary and new agrochemical products-[kt VOC]	0	160.0	55.0

21.6.3 Beyond business as usual potential abatement measures

New agrochemicals products have been developed with lower solvent contents. In the absence of specific data, it is assumed that 50% of the sector could switch to these new products. Therefore, the additional emissions reductions that could be potentially achieved are as follows:

- Additional uptake of control with new products for 25% of emissions not controlled in 2030 could reduce emissions by 0.2kt at a cost of £3,000 per year (around £15/t).
- Additional uptake of control with primary and new products for 25% of emissions not controlled in 2030 could reduce emissions by 0.5kt at a cost of £71,000 per year (around £130/t).

21.6.4 Summary of measures and costs

Table A21.18 summarises the estimated cost of each abatement technology for the agrochemicals sector. The costs are summarised above and are per tonne VOC abated, as no data on capital and operating costs was available.

Table A21.19 presents the reduction efficiency of the abatement measures and the associated reduction in emissions.

Table A21.22 Summary of beyond BAU abatement measures for the agrochemicals sector

Abatement measure	Future uptake of measure (%)		Operating life (years)	Capital Costs (£k, 2011 prices)		Annual operating costs (£k, 2011 prices)		Total annualised costs (£kpa, 2011 prices)	
	2025	2030		2025	2030	2025	2030	2025	2030
Uptake of new agrochemicals products	25%	25%	-	-	-	-	-	2.84	2.84
Uptake of new and primary agrochemicals products	25%	25%	-	-	-	-	-	71.13	71.13

Note 1: A discount rate of 3.5% is considered in the analysis.

Table A21.23 Summary of beyond BAU abatement measures efficiency for the agrochemicals sector

Abatement measure	Emission reduction efficiency (%)	Reduction in 2025 emissions (kt)	Reduction in 2030 emissions (kt)
	VOC	VOC	VOC
Uptake of new agrochemicals products	20.0%	0.19	0.19
Uptake of new and primary agrochemicals products	55.0%	0.53	0.53

21.6.5 References

1. GAINS model

A21.7 Animal feed manufacture, margarine and other solid fats production

21.7.1 Sector Profile

Table A21.24 presents the emissions for the animal feed, margarine and other solid fats production sector developed by AEA, based on DECC's UEP 43 forecasts (with 2009 baseline NAEI emissions).

Table A21.24 Emissions of VOCs from animal feed manufacture, margarine and other solid fats production and relative contribution to UK emissions for 2030

Source Name	Activity Name	Emissions (kt)	% of total UK VOC emissions
Other food - animal feed manufacture	Animal feeds	10.35	1%
Other food - margarine and other solid fats	Fats	5.08	1%

21.7.2 Business as usual policies and abatement measures

The production of crude vegetable oil from oilseeds (e.g. soya beans, sunflower seeds or rapeseed) is a two-stage process:

- The first process step is the cleaning, preparation (i.e. drying) and in some cases dehulling, flaking and conditioning and pressing of the oilseeds. Pressing takes place in one or two steps, resulting in crude pressed oil and a cake. Beans (with 20% oil or less) are not pressed, because of the lower fat content, but are extracted directly after cleaning and preparation.

- The second process step is the extraction of oil from the pressed cake or flaked beans using hexane as a solvent. Extraction takes place in counter-current flow.

The mixture of hexane and oil, called miscella, is further processed in a distillation process, to recover the hexane from the vegetable oil. The solvent is re-used in the extraction process. The hexane remaining in the cake is recovered by a stripping process, using steam. This process also reduces the enzyme and micro organism activity in the meal. The meal is dried and cooled by air before storage in silos or before loading. This activity emits NMVOC originating from the use of hexane.

Vegetable oil activities are addressed by the Solvent Emission Directive (SED, now part of the Industrial Emissions Directive)[5]. Operators can conform to the Directive by introducing a reduction scheme to comply with the total emission limit values as defined in table below. The SED applies to installations with a solvent consumption above 10 t per year.

Table A21.25 Emission limit values for fat-oil

Measures	Emission limit values
Rapeseed / sunflower seed	1.0
Soya beans (normal crush)	0.8
Soya beans (white flakes)	1.2
Animal fat	1.5
Olives	1.5
Castor / other seed and other vegetable matter	2.5

The discussion below is based on the methodology developed by the “Expert Group on Techno-Economic Issues” (EGTEI), the work of which has subsequently been included in the GAINS model[6].

EGTEI states that standard techniques used by the industry are a combination of condensation/physical separation/distillation and absorption/desorption. These techniques are not applied as independent techniques but in an interconnected way. Two primary measures are considered based on different processes: two types of desolventiser can be used (i.e. the traditional one and the Schumacher type desolventiser-toaster-dryer-cooler). Hexane recovery unit is the unique secondary measure considered for this sector. This technique is well adapted to recover the hexane used. Its use allows installations to comply with the SED requirements.

The GAINS model identifies three measures for VOC abatement in the animal feeds and margarine and other solid fats production sector, shown in Table A21.26.

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[5] Council Directive 1999/13/EC of 11 March 1999 on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain activities and installations.

[6] http://citepaax.alias.domicile.fr/forums/egtei/37-Synopsis-sheet-fat-edible-30-09-05.pdf

Table A21.26 Measures in GAINS for animal feeds and margarine and other solid fats production

Measures	% of total activity controlled in 2030	Euro/t_VOC abated	Removal efficiency (%)	Reason for selection
Seeds-Fat, edible and non-edible oil extraction-Activated carbon adsorption	90	-757.819	73.0	Not selected – already BAU
Seeds-Fat, edible and non-edible oil extraction-Schumacher type desolventiser-toaster-dryer-cooler plus an old hexane recovery section	10	-783.541	80.0	Cost-effective option/ high abatement efficiency
Seeds-Fat, edible and non-edible oil extraction-Schumacher type desolventiser-toaster-dryer-cooler plus a new hexane recovery section and process optimization	0	-780.013	83.0	Cost-effective option/ high abatement efficiency

21.7.3 Beyond business as usual potential abatement measures

According to EGTEI (2005), as the standard combination of control techniques based on Best Available Techniques (BAT) is being used across the whole sector, the only possibility for these installations to further reduce VOC emissions and remain in compliance with the SED is improved process control, process optimisation and autonomous minor process modifications, as well as proper maintenance of existing installations.

The combination of the Schumacher type desolventiseter unit plus a new hexane recovery section can be defined as BAT (EGTEI, 2005). Therefore, the additional emissions reductions that could be potentially achieved are as follows:

- Additional uptake of Schumacher type desolventiser-toaster-dryer-cooler plus an old hexane recovery section for 40% of emissions not controlled in 2030 could reduce emissions by 5kt at a cost of £3.2m (around £650/t).

- Additional uptake of Schumacher type desolventiser-toaster-dryer-cooler plus a new hexane recovery section and process optimization for 50% of emissions not controlled in 2030 could reduce emissions by 6.4kt at a cost of £4.2m (around £650/t).

21.7.4 Summary of measures and costs

Table A21.27 summarises the estimated cost of each abatement technology for the sector. The costs are summarised above and are per tonne VOC abated, as no data on capital and operating costs was available.

Table A21.28 presents the reduction efficiency of the abatement measures and the associated reduction in emissions.

Table A21.27 **Summary of beyond BAU abatement measures for the animal feeds manufacture, margarine and other solid fats production sector**

Abatement measure	Future uptake of measure (%)		Operating life (years)	Capital Costs (£k, 2011 prices)		Annual operating costs (£k, 2011 prices)		Total annualised costs (£kpa, 2011 prices)	
	2025	2030		2025	2030	2025	2030	2025	2030
Schumacher type desolventiser plus old hexane recovery	40%	40%	-	-	-	-	-	-3,240	-3,240
Schumacher type desolventiser plus new hexane recovery	50%	50%	-	-	-	-	-	-4,183	-4,183

Note 1: A discount rate of 3.5% is considered in the analysis.

Table A21.28 **Summary of beyond BAU abatement measures efficiency for the animal feeds manufacture, margarine and other solid fats production sector**

Abatement measure	Emission reduction efficiency (%)	Reduction in 2025 emissions (kt)	Reduction in 2030 emissions (kt)
	VOC	VOC	VOC
Schumacher type desolventiser plus old hexane recovery	80.0%	4.94	4.94
Schumacher type desolventiser plus new hexane recovery	83.0%	6.40	6.40

21.7.5 References

1. EGTEI (2005) Fat, edible and non-edible oil extraction: synopsis sheet. Prepared in the framework of EGTEI.

A21.8 Industrial Coatings - Wood, Metal & Plastics

21.8.1 Sector Profile

Table A21.29 presents the emissions for the industrial coatings sector developed by AEA, based on DECC's UEP 43 forecasts (with 2009 baseline NAEI emissions).

Table A21.29 Emissions of VOCs from industrial coatings and relative contribution to UK emissions for 2030

Source Name	Activity Name	Emissions (kt)	% of total UK VOC emissions
Industrial coatings – metal and plastic	Metal and plastic coating	14.33	2%
Industrial coatings - wood	Wood coating	5.00	1%

Industrial coatings also contribute to emissions of particulate matter as summarised in the table below.

Table A21.30 Emissions of PM from industrial coatings and relative contribution to UK emissions for 2030

Source Name	Activity Name	Emissions (kt)		% of total UK emissions	
		PM10	PM2.5	PM10	PM2.5
Industrial coatings - agricultural and construction	Ace coatings	0.14	0.05	0.14%	0.10%
Industrial coatings - aircraft	Aircraft coatings	0.12	0.04	0.11%	0.08%
Industrial coatings - automotive	Automotive coatings	0.91	0.32	0.87%	0.64%
Industrial coatings - commercial vehicles	Commercial vehicle coatings	0.27	0.10	0.26%	0.19%
Industrial coatings - drum	Drum coatings	0.039	0.01	0.04%	0.03%
Industrial coatings - high performance	High performance coatings	0.38	0.13	0.36%	0.26%
Industrial coatings - marine	Marine coatings	0.17	0.06	0.17%	0.12%
Industrial coatings - metal and plastic	Metal and plastic coatings	1.39	0.49	1.32%	0.97%

Source Name	Activity Name	Emissions (kt)		% of total UK emissions	
Industrial coatings - vehicle refinishing	Vehicle refinishing coatings	0.41	0.14	0.39%	0.29%
Industrial coatings - wood	Wood coatings	0.28	0.10	0.26%	0.19%

Whilst overall industrial coatings make a significant contribution to PM emissions, only one sub-source contributes over 1% to total UK PM10 emissions in 2030 and no sources contribute over 1% for PM2.5. We have undertaken some initial research into possible measures for the control of PM emissions from the sector but it has not been feasible within the scope of the study to identify sufficient cost and other data to develop PM specific measures. Therefore, the focus of this chapter is on controlling emissions of VOCs from industrial coatings (although these measures may also have an impact on PM emissions).

21.8.2 Business as usual policies and abatement measures

A coating is a covering that is applied to a surface or substrate. Coatings are used for decorative, protective and functional treatments of a wide array of surfaces. Industrial coatings are taken herein to include paint or coatings defined by their protective properties, rather than their aesthetic properties, although such coatings often provide both.

Coating activities are in the scope of the Solvent Emission Directive (SED, now part of the Industrial Emissions Directive)[7]. In addition, some installations with larger capacity and throughput have been subject to the requirements of the IPPC Directive (also now part of the Industrial Emissions Directive).

In the UK, many industrial coatings processes are regulated under the Local Authority Pollution Prevention and Control regime. Under LAPPC, installations covered are required to minimise air pollution through conditions set out in a permit. For some sectors, a permit is only required for installations above a certain size. Guidance for local authorities on the content of permits is provided through Process Guidance Notes[8]. Permits should also include the requirements of the SED, where applicable.

The SED requires installations in which defined coating activities are undertaken to comply either with emission limit values set out in the Directive or with the requirements of the so-called reduction scheme. The Directive sets

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[7] Council Directive 1999/13/EC of 11 March 1999 on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain activities and installations.

[8] PGNs are produced for the majority of the coating sub-sectors included herein, including: chemical treatment of timber and wood-based products; printing and coating of metal packaging; textile and fabric coating and finishing; coil coating; film coating; coating in drum manufacturing and reconditioning; paper coating; paint application in vehicle manufacturing; leather finishing; coating of metal and plastic; wood coating; original coating of road vehicles and trailers; respraying of road vehicles; coating and recoating of aircraft and aircraft components; coating and recoating of rail vehicles.

out emission limit values for VOCs in waste gases and maximum levels for fugitive emissions (expressed as percentage of solvent input) or total emission limit values. The reduction scheme allow installations undertaking certain processes to achieve equivalent emissions reductions by minimising VOC solvent usage (through reaching a target that takes into account the total mass of solids in the coating used annually, a fixed multiplication factor and a percentage based on the emission limit values). The purpose of the reduction scheme is to allow the operator to achieve emission reductions by other means, equivalent to those achieved if the emission limit values were to be applied. This could be typically achieved by substituting products that have a high content of solvents with low-solvent or solvent-free products and changing to solvent free production processes. Table A21.31 below presents the thresholds, emission limit values and fugitive emission values for wood coating activities under the SED.

Table A21.31 Requirements for wood, metal and plastic coating activities under the solvent emissions directive

Activity (as described in the SED)	Threshold (solvent consumption threshold; tonnes per year)	Emission limit values in waste gases (mg C/Nm^3)	Fugitive emission values (percentage of solvent input)
Other coating, including metal, plastic, textile, fabric, film and paper coating	5-15	100	25
	>15	50/75 (Note 1)	20
Coating of wooden surfaces	15< <25	100	25
	>25	50/75 (Note 1)	20

Note 1: The first value applies to drying processes, the second to coating application processes.

The BREF note on surface treatment using organic solvents (EC, 2007) indicates several techniques relevant to reducing VOC emissions for relevant sectors. Amongst these, switching from conventional solvent-based coatings to solvent-based high solid coatings is deemed widely applicable and already applied to metals, but is not generally applicable to wooden surfaces. Water-based coatings could achieve important reductions of VOCs, but are more difficult to dry than solvent-based coatings and can have poor application efficiency; they also do not provide sufficient protection in aggressive environments (including water). Due to continuous development in these materials, their range of application is constantly increasing. Powder coatings are already well established and do not generate any VOC emission, and could potentially be developed further and applied more widely.

Moreover, several application techniques with improved transfer efficiency could be used, although they are very dependant on the object to be coated. Indeed, higher transfer efficiency spray techniques (e.g. high-volume low pressure spray guns). For wood coating, the BREF indicates that the use of an application method with increased efficiency can decrease VOC emissions by nearly half (from 80 – 100 g/m^2 to 40 – 60 g/m^2). Furthermore, when using a high efficiency application method, a decrease in the coating's solvent content from a high content to a medium and then low content can decrease emissions dramatically (from 40 – 60 g/m^2 to 10 – 20 g/m^2 and 2 – 5 g/m^2 respectively). However, it is not clear to what extent companies across the sector could additionally implement these application methods or use coatings with lower solvent content (and the current market penetration is unknown).

The EGTEI background document for coating of wood splits the sector between very small, small, medium and large installations, depending on the annual surface coated. This document also gives costs for implementation of an application method with higher efficiency. However, the two documents do not use the same definitions as high solvent content coating is defined as 65% solvent in the BREF document and 80% in the EGTEI background document.

An approach similar to the one used in the EGTEI document has been used in the GAINS model, giving efficiencies for VOC abatement measures. These measures considered coatings with different levels of solvent content, in association with two different application efficiencies, as well as incineration. Table A21.32 summarises the measures presented in the GAINS model with their abatement efficiency. The baseline used for calculating the efficiency is the use of low solid systems (80% solvent content) applied with an efficiency of 35%.

Table A21.32 Summary of measures and associated abatement efficiency in the GAINS model[1] for wood coating

Abatement measure	Abatement Efficiency (%)
Low solids systems (80% solvent content) – application efficiency of 75%	53[2]
Medium solid systems (55% solvent content) – application efficiency of 75%	86.6
High solid systems (20% solvent content) – application efficiency of 35%	93.75
High solid systems (20% solvent content) – application efficiency of 75%	97.2
Very high solid systems (5% solvent content) – application efficiency of 35%	98.6
Very high solid systems (5% solvent content) – application efficiency of 75%	99.3
Incineration	76

1) Scenario NEC_NAT_MRRV4 - (http://www.iiasa.ac.at/webapps/apd/gains/cost.EU/index.menu)

2) Scenario NEC_NAT_CLEV4

For metal and plastic coatings, the GAINS model includes a number of possible measures which were reviewed with three measures selected to be developed for the MPMD.

Table A21.33 Summary of measures and associated abatement efficiency in the GAINS model[1] for metal and plastic coating

Measures	% of total activity controlled in 2030	Euro/t_VOC	Removal efficiency (%)	Reason for selection
Paint use-Industrial paint applications - General industry (continuous processes)-Incineration-[kt]	0	26,795.2	76	Not selected

Measures	% of total activity controlled in 2030	Euro/t_VOC	Removal efficiency (%)	Reason for selection
Paint use-Industrial paint applications - General industry (continuous processes)-Use of improved solvent based paints (55%), application efficiency as above-[kt]	25	-173.1	37.4	Not selected
Paint use-Industrial paint applications - General industry (continuous processes)-Combination of the above options-[kt]	30	20,909.1	85	Not selected
Paint use-Industrial paint applications - General industry (continuous processes)-Powder coating system (solvent free)-[kt]	15	-2,373.3	100	Most cost-effective option/ Highest abatement efficiency
Paint use-Industrial paint applications - General industry (continuous processes)-Use of water based paints (5%): application efficiency as above-[kt]	28.5	715.9	95.3	Not selected
Paint use-Industrial paint applications - General industry-Use of current standard solvent based paints (60% solvent content) and application efficiency 65%-[kt]	19	-2,729.1	50.6	Not selected
Paint use-Industrial paint applications - General industry-Combination of the above options-[kt]	0	19,786.1	88.1	Not selected
Paint use-Industrial paint applications - General industry-Incineration-[kt]	0	34,046.2	76	Not selected
Paint use-Industrial paint applications - General industry-Use of improved solvent based paints (55%), application efficiency as above-[kt]	20	-3,719.5	74.5	Not selected
Paint use-Industrial paint applications - General industry-Combination of the above options-[kt]	0	11,676.7	93.9	Not selected
Paint use-Industrial paint applications - General industry-Powder coating system (solvent free)-[kt]	30	-5,379.0	100	Most cost-effective option/ Highest abatement efficiency
Paint use-Industrial paint applications - General industry-Use of water based paints (5%): application efficiency as above-[kt]	15	-1,286.2	95.9	Not selected
Paint use-Industrial paint applications - General industry (plastic parts)-Use of current standard solvent based paints (60% solvent content) and application efficiency 65%-[kt]	25	-5,220.3	59.2	Not selected
Paint use-Industrial paint applications - General industry (plastic parts)-Combination of the above options-[kt]	0	4,005.5	90.2	Not selected
Paint use-Industrial paint applications - General industry (plastic parts)-Incineration-[kt]	0	15,269.3	76	Not selected
Paint use-Industrial paint applications - General industry (plastic parts)-Use of improved solvent based paints (55%), application efficiency as above-[kt]	0	-5,091.8	66.7	Not selected
Paint use-Industrial paint applications - General industry (plastic parts)-Combination of the above options-[kt]	9.8	3,632.7	92	Not selected
Paint use-Industrial paint applications - General industry (plastic parts)-Powder coating system (solvent free)-[kt]	0	-4,993.4	100	Most cost-effective option/ Highest abatement efficiency

Measures	% of total activity controlled in 2030	Euro/t_VOC	Removal efficiency (%)	Reason for selection
Paint use-Industrial paint applications - General industry (plastic parts)-Use of traditional solvent based paints but improved application efficiency up to 65%-[kt]	0	-5,820.1	46.2	Not selected
Paint use-Industrial paint applications - General industry (plastic parts)-Combination of the above options-[kt]	0	4,919.8	87.1	Not selected
Paint use-Industrial paint applications - General industry (plastic parts)-Use of water based paints (5%): application efficiency as above-[kt]	40	-2,244.9	96.4	Not selected

21.8.3 Beyond business as usual potential abatement measures

It has been assumed that the control strategy presented in the GAINS model could be applied to UK emissions projections. As agreed with Defra, the three most cost-effective/highest abatement efficiency measures were taken forward as BBAU for wood coatings and for metal and plastic coatings. The additional emission reductions that could be potentially achieved are as follows:

- For wood coatings:
    - Additional uptake of control with use of low solid system and high application efficiency techniques for 22% of use in 2030. This could reduce emissions by 0.6kt with a saving of £1.5m per year (£2,500/t).
    - Additional uptake of control with use of high solids system and high application efficiency techniques for 10% of use in 2030. This could reduce emissions by 0.5kt with a saving of £890k per year (£1,800/t).
    - Additional uptake of control with use of very high solids system and high application efficiency techniques for 67% of use in 2030. This could reduce emissions by 3.3kt with a saving of £6.1m per year (£1,850/t).
- For metal and plastic coatings the application of solvent free powder coating systems for different processes/parts of the industry have been considered:
    - Continuous processes for 35% of use in 2030. This could reduce emissions by 5.0kt with a saving of £10m per year.
    - General industry for 20% of use in 2030. This could reduce emissions by 2.9kt with a saving of £13m per year.
    - Coating of plastic parts for 50% of use in 2030. This could reduce emissions by 7.2kt with a saving of £30m per year.

Negative annual costs indicate operational savings that could be due to energy savings or more efficient use of raw materials. However, the up-front capital costs incurred for the implementation of these measures may be significant thus deterring companies from making the investment.

21.8.4 Summary of measures and costs

Table A21.34 summarises the estimated cost of each abatement technology for the wood coatings sector. The costs are summarised above and are per tonne VOC abated, as no data on capital and operating costs was available.

Table A21.35 presents the reduction efficiency of the abatement measures and the associated reduction in emissions.

Table A21.34 Summary of beyond BAU abatement measures for the wood, metal and plastic coatings sector

Abatement measure	Future uptake of measure (%)		Operating life (years)	Capital Costs (£k, 2011 prices)		Annual operating costs (£k, 2011 prices)		Total annualised costs (£kpa, 2011 prices)	
	2025	2030		2025	2030	2025	2030	2025	2030
Wood coatings - High solids coating systems	10.4%	10.4%	-	-	-	-	-	-890	-890
Wood coatings - Low solid coating systems	22.2%	22.2%	-	-	-	-	-	-1,475	-1,475
Wood coatings - Very high solid systems	66.7%	66.7%	-	-	-	-	-	-6,119	-6,119
Metal and plastic coatings - Continuous processes - powder coating system	35.0%	35.0%	-	-	-	-	-	-9,972	-9,972
Metal and plastic coatings - General industry - powder coating system	20.0%	20.0%	-	-	-	-	-	-12,916	-12,916
Metal and plastic coatings - Plastic parts - powder coating system	50.0%	50.0%	-	-	-	-	-	-29,974	-29,974

Note 1: A discount rate of 3.5% is considered in the analysis.

Table A21.35 Summary of beyond BAU abatement measures efficiency for the wood, metal and plastic coatings sector

Abatement measure	Emission reduction efficiency (%)	Reduction in 2025 emissions (kt)	Reduction in 2030 emissions (kt)
	VOC	VOC	VOC
Wood coatings - High solids coating systems	97.2%	0.50	0.50
Wood coatings - Low solid coating systems	52.8%	0.59	0.59
Wood coatings - Very high solid systems	99.3%	3.31	3.31
Metal and plastic coatings - Continuous processes - powder coating system	100.0%	5.02	5.02
Metal and plastic coatings - General industry - powder coating system	100.0%	2.87	2.87
Metal and plastic coatings - Plastic parts - powder coating system	100.0%	7.16	7.16

21.8.5 References

1. EC (2007): Reference Document on Best Available Techniques on Surface Treatment using Organic Solvents (August 2007)

2. EGTEI (2003): Wood coating, Final Background Document on the sector (June 2003).

A21.9 Decorative Paints

21.9.1 Emissions

The decorative paint sector is split into the retail and trade sectors. The table below summarises the contribution these sources make to total UK VOC emissions in 2030.

Table A21.36 Source of VOC and relative contribution to UK emissions in 2030

Source	Kt per year	% of UK total
1A4ai_Decorative paint - retail decorative_Retail decorative coatings	16.48	2.5
1A1b_Decorative paint - trade decorative_Trade decorative coatings	10.62	1.6

A21.10 Abatement measures in GAINS

Only one measure is identified in the GAINS model, however BAU uptake is assumed to be 100% in 2030 as shown in Table A21.37. Therefore no measures have been developed for inclusion in the MPMD for this source of VOC emissions.

Table A21.37 Measures in GAINS

Measures	% of total activity controlled in 2030	Euro/t_VOC	Removal efficiency (%)
Paint use-Decorative paints-Simulation of possible developments beyond Product Directive-[kt]	100	1550.5	65.9

A21.11 Whisky and Other Spirits Industry

21.11.1 Sector profile

According to the Scotch Whisky Association (SWA), Scotch whisky currently accounts for a quarter of UK food and drink exports and earned £3.45bn for the UK balance of payments in 2010 (SWA,2012). The sector is also responsible for a number of sources of VOC emissions, which occur during the fermentation, distillation, casking, spent grain drying and maturation processes.

The NAEI emission projections, based on DECC's UEP43 forecasts and the 2009 baseline, indicate that the main source of VOC emissions is from the Scotch whisky in storage during the maturation process, when it is aged in oak barrels. This is projected to contribute 49.34 kt of VOCs in 2025, remaining stable to 2030. These projected emissions correspond to around 7.4% of total UK projected VOC emissions in 2025-2030. Whilst VOC emissions also occur during the other stages of the production process, measures for VOC control from these sources have not been investigated as these are not considered significant (<1% of total emissions). It is also considered that releases during the distillation and casking stages are largely controlled, as these equate to a loss of profit for the industry.

21.11.2 Policies and abatement measures

There are no abatement measures for this source in the GAINS model. There are currently no known regulations or abatement measures in place for the sector.

According to the 2003 BREF for the food, drink and milk sector, in order to improve efficiency and lower energy consumption, emissions shall be enclosed as much as possible and ducted for treatment. Sealing of warehouses and installation of ducting and treatment of emissions would mean substantial design changes to existing warehouses. This kind of work is not permitted by health and safety legislation in warehouses containing filled casks. Removing casks from the warehouses during the work could be a solution, but the impact on quality of the product is unknown and testing the effect on quality would require a research period equivalent to the length of the maturation process i.e. 3-15 years minimum.

During consultation in the previous work phase, the Scotch Whisky Association (SWA) indicated that *"reduction measures would comprise of 2 components. Firstly, the bonded warehouses would have to be made air-tight to prevent fugitive emissions. The buildings currently are old and of traditional construction, so it is unlikely that they could be modified to meet the criteria. Therefore a new generation of bonded warehouses would likely be required with additional construction requirements e.g. sealed double door access points. Secondly, the warehouse air would need to be collected and abated to remove the ethanol emissions"* (SWA 2008). They noted that, to completely seal all maturation warehouses in the Scotch Whisky industry alone, industry estimates made in 1996 give a cost of around £2 billion, (i.e. just over £3 billion in 2011 prices).

Beyond the cost of such work and its unknown feasibility, the impact of sealed warehouse on the quality of the future product is feared to be undesirable by the SWA, which indicates that *"a free and uninterrupted flow of air around maturation warehouses is essential for product quality and for quality control reasons"*.

It has been agreed with Defra that no measure therefore be developed for this sector.

21.11.3 References

1. SWA (2012) News Release. The People behind Scotch Whisky - Employment report published, Available online at http://www.scotch-whisky.org.uk/swa/files/jobsreportFIINALnewsreleaseTOUSE.pdf [Accessed on 21/03/12]

2. SWA (2008): Personal communication with Scotch Whisky Association on 20th May 2008.

A21.12 Surface cleaning

21.12.1 Sector profile

The table below presents the emissions from surface cleaning developed by AEA, based on DECC's UEP 43 forecasts (with 2009 baseline NAEI emissions).

Table A21.38 Emissions of VOCs from surface cleaning and relative contribution to UK emissions for 2030

Source Name	Activity Name	Emissions (kt)	% of total UK VOC emissions
Surface cleaning - 111-trichloroethane_Cleaning solvent	Cleaning solvent	0.00	0.0%
Surface cleaning - dichloromethane_Cleaning solvent	Cleaning solvent	0.16	0.0%
Surface cleaning - hydrocarbons_Cleaning solvent	Cleaning solvent	16.68	2.5%
Surface cleaning - oxygenated solvents_Cleaning solvent	Cleaning solvent	3.57	0.5%
Surface cleaning - tetrachloroethylene_Cleaning solvent	Cleaning solvent	0.24	0.0%
Surface cleaning - trichloroethylene_Cleaning solvent	Cleaning solvent	1.60	0.2%

21.12.2 Business as usual policies and abatement techniques

Surface cleaning is subject to the Solvent Emissions Directive (SED)[9]. The table below presents the requirements for these activities. Some installations are also subject to LAPC/LAPPC requirements.

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[9] Council Directive 1999/13/EC of 11 March 1999 on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain activities and installations.

Table A21.39 Requirements for relevant activities under the solvent emission directive

Activity (as described in the SED)	Threshold (solvent consumption threshold tonnes per year)	Emission limit values in waste gases (mg C/Nm^3)	Fugitive emission values (percentage of solvent input)
Surface cleaning using substances or preparations assigned risk phrase R45, R46, R49, R60, R61 or discharging halogenated VOCs assigned R40 in specific conditions[1]	1 - 5	20 (refers to mass of compounds in mg/Nm^3, not to total carbon)	15
	>5	20 (idem)	
Other surface cleaning	2 - 10	75	20
	>10	75	15

Note 1: Discharges of halogenated VOCs assigned the risk phrase R40 where the mass flow of the sum of the compounds causing the labelling R40 is greater than, or equal to, 100 g/h

Process guidance note PG6/45(04) indicates low organic solvent and low volatility organic solvent cleaning solutions and the use of enclosed systems or open-topped degreasers as techniques to comply with the SED.

Previous work by Entec (2003) indicates that alternative cleaning solutions (such as aqueous systems) and closed systems fitted with carbon adsorption were thought to be applied to some uses across all sectors for compliance either with the LAPC requirements or later with the SED.

Projections show a sharp fall in emissions from processes involving trichloroethylene and hydrocarbons between 2007 and 2010. These may be explained by compliance with the requirements of the SED, which had to be achieved by October 2007. In addition, since the SED was introduced in 1999, there has been a requirement to substitute the most hazardous solvents with alternatives within the "shortest possible time" (in practice interpreted as by October 2007 at the latest). This could be at least partly responsible for the significant decline in trichloroethylene emissions over the intervening period.

Action has also been taken to reduce/eliminate use of trichloroethylene or to encourage conversion to fully enclosed systems on the grounds of health and safety. Members of the main European trade association have signed a product stewardship which commits signatories to selling trichloroethylene only to end-users with enclosed equipment, thus minimising workplace exposure. Signatories will phase out sales of trichloroethylene for open metal cleaning systems by 31 December 2010[10]. Guidance has also been provided by relevant industry associations, and Government departments in the UK[11].

It is noted that compliance with the Solvent Emissions Directive is unlikely to be 100% because of the difficulty in identifying some of the smaller engineering firms which undertake surface cleaning, despite various efforts locally and nationally to do so. This may mean that some (expected to be small) proportion of the emissions reductions are not achieved.

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[10] New charter for safe use of trichloroethylene in metal cleaning, 29 June 2007, Eurochlor website (http://www.eurochlor.org/news/detail/index.asp?id=232), accessed 17 April 2009.

[11] Guidance on the use of Trichloroethylene as a vapour degreasing solvent. SEA, EEF, Defra and HSE.

21.12.3 Beyond business as usual potential abatement measures

The BREF note on surface treatment using solvents (EC, 2007) mentions use of water under high pressure, ultrasonic cleaning and dry ice (CO_2) as alternative techniques in addition to techniques using solvent. The EGTEI background document (EGTEI, 2005) describes different techniques for surface cleaning. In addition to aqueous systems and closed systems, other options presented are:

- Cold cleaners are degreasers using a batch of non-boiling solvent. Parts to be cleaned are typically sprayed or dipped in the solvent. These degreasers are intended to be covered when not in use.
- Plasma degreasing is already applied in some specific production sectors and can be applied to a large variety of substrates leading partly to even better cleaning results than former solvent systems. The ionised gas particles created in this system generate radicals, which aim at cutting the hydrocarbon chains and oxidise them to form CO_2 and water. However, this technique, efficient with organic impurities, is not suitable for inorganic impurities such as dusts and salts.
- Biological cleaning processes are based on a water-based cleaning agent combined with an integrated microbiology for the degradation of oils and grease. In this technique the control of the medium is of high importance, in order not to harm the micro-organisms used. Thus a temperature of 40-45^{o}C and a pH of 9 have to be maintained throughout the process.
- Supercritical CO_2: at a supercritical state (beyond 75 bars and 35^{o}C), CO_2 has adjustable solvent properties with variations of temperature and pressure, and is easily recoverable by evaporation. However, this technique works well for non-polar products but has to be modified for polar products, for example through the addition of a co-solvent or the use of mechanical action such as ultra-sound.

Based on a review of previous work to develop cost curves for VOCs by Entec (2003), measures in the GAINS model and the EGTEI background document on surface cleaning no suitable beyond business as usual measures have been identified for this study.

21.12.4 References

1. EC, 2007: Reference Document on Best Available Techniques on Surface Treatment using Organic Solvents (August 2007)

2. Entec, 2003: Revision of Cost Curve for VOCs. A report for Defra (March 2003)

3. EGTEI, 2005: Final Background Document on Surface cleaning (May 2005)

4. Defra, 2004: Process guidance note 6/45 on Surface cleaning (March 2004)

A21.13 Road dressings (non-fuel bitumen use)

21.13.1 Sector profile

The table below presents the emissions from road dressings (bitumen – also known as asphalt or tarmac – used for surfacing and resurfacing roads) developed by AEA, based on DECC’s UEP 43 forecasts (with 2009 baseline NAEI emissions).

Table A21.40 Emissions of VOCs from road dressings and relative contribution to UK emissions for 2030

Source Name	Activity Name	Emissions (kt)	% of total UK VOC emissions
Road dressings_Non fuel bitumen use	Road dressings	8.03	1.2%

21.13.2 Possible measures

One measure is given in the GAINS model, although a removal efficiency of 0.0% is given, and no cost data recorded. This is likely to mean that the measure is not deemed applicable for the UK.

According to European Asphalt Pavement Association and the US National Asphalt Pavement Association, ‘cutback bitumen has been largely replaced with the more environmentally friendly bitumen emulsion’ (EAPA and NAPA, 2011). The extent to which this is the case in the UK would require further investigation, along with actual VOC reduction and associated costs.

An alternative measure is switching to concrete, although this would lead to an increased indirect CO_2 impact (roughly twice, based on a CO_2e/m3 comparison of concrete and an average asphalt value using the Environment Agency construction CO_2 calculator). It is likely to also lead to increased tyre wear PM emissions (Arizona Department of Transportation, 2006).

It was agreed with Defra that no beyond BAU measures would be developed at this stage.

A22. Contents

A22.Agriculture

A22.1 Sector profile

The NAEI emission projections for agriculture, based on DECC’s UEP43 forecasts and the 2009 baseline, indicate that the key source of PM emissions are from the following housed livestock: broilers, pigs and other poultry.

Whilst the emission projections suggest that other agricultural sources such as laying hens also contribute to PM emissions, they are not considered significant (<1% of total UK emissions), therefore measures for PM control from these sources have not been investigated.

The sources to be investigated, along with their respective contributions to emission totals are shown in Table A22.2.

Table A22.1 Sources to be investigated for agriculture

Source (NFR – Sector – activity)	Contribution in 2030
PM_{10}	
0_Agriculture livestock - broilers_Housed livestock	6%
0_Agriculture livestock - other poultry_Housed livestock	2%
0_Agriculture livestock - pigs_Housed livestock	1%
$PM_{2.5}$	
1A2fi_Agriculture livestock - broilers_Housed livestock	2%
1A2fii_Agriculture livestock - other poultry_Housed livestock	1%

Emissions from these sources are projected to remain constant between 2010 and 2030.

Research for this study has highlighted a degree of debate around the potential accuracy of the PM emission factors in the NAEI, which have remained constant over the past decade. A related point concerns the outstanding need to integrate progress on ammonia and PM abatement, as a number of technical measures aimed at ammonia can also impact on PM. The Environment Agency is currently looking into issues related to PM10 emission from intensive farming installations under their jurisdiction, and expect to undertake this research over the coming year. Altogether, this means that whilst measures have been worked up in the current MPMD update, the projected contributions of these sources in 2030 in the underlying NAEI baseline projections merit further attention and consideration in due course.

A22.2 Business as usual policies and abatement measures

Currently, the main policy drivers for controlling air quality impacts of the sector are the Integrated Pollution Prevention and Control (IPPC) Directive which has been replaced by the Industrial Emissions Directive (IED, 2010/75/EU). The IED will be transposed into UK legislation by January 2013. Other relevant policy drivers include the 1999 UNECE Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone and its recent revision. Whilst the IED places a greater emphasis on the application of BAT and makes it much harder to deviate from the definition of BAT in the BREF (and subsequent BAT Conclusions), a revised version of the BREF for intensive livestock (2003) is not yet available (although the review process has started). Therefore, it is unclear what impacts the IED could have on the sector over and above the existing IPPC regime.

The requirements established in the permitting regime under the IPPC approach have led to some uptake of good housekeeping measures for pig and poultry rearing, although it has not been possible to establish the extent of this due to data constraints. The Environment Agency (2011) sets out various good housekeeping measures for particulate reduction in poultry farms, which can be done both at source and at release to the atmosphere. The guidance document states that some dust control at source methods - such as those used inside a poultry building - have limited abatement efficiencies, and that “[i]t is therefore debatable how practical or economical it is to use control at source abatement techniques as specific ‘stand-alone’ dust control methods in a poultry house.” It also states that “[m]any techniques may well already make a contribution to dust control where they are part of normal flock management techniques” such as good quality feed pellets fed to birds using modern feeders (i.e. ones that do not break up the feed and are not over-filled) and properly cleaning houses and equipment on a regular basis. Dust extracted bedding material is effective, and “better for the birds, more bio-secure and affordable”.

“End of pipe” measures are also shown to be effective in treating both particulate and ammonia emissions, both in trials and in the commercial industry according to the guidance. However, they require a “significant capital outlay on systems with high air change rates and may have high running costs”.

A22.3 Beyond business as usual potential abatement measures

22.3.1 Overview

Based on a review of the Gothenburg Protocol revision supporting documentation, the latest draft of the revised IPPC Reference Document on Best Available Techniques (BREF) for The Intensive Rearing of Poultry and Pigs Draft 1- March 2011 (EC, 2011) and further publications from the Environment Agency, a common general approach has been implemented for all three sources of emissions. According to EMEP/EEA (2010), techniques to reduce airborne dust in livestock buildings include:

> [m]easures such as wet feeding, including fat additives in feed, oil and/or water sprinkling… End-of-pipe technologies are also available to reduce PM emissions significantly, in particular filters, cyclones, electrostatic precipitators, wet scrubbers or biological waste air purification systems. While many of these

are currently considered too expensive, technically unreliable or insufficiently user-friendly to be widely adopted by agriculture, air scrubbers are considered to be category 1 abatement options by the UNECE (2007).

Several air scrubber options have been assessed on the basis of data availability, applicability and the UNECE classification. These are applied to larger scale operations, defined as those above IED thresholds. The data for air scrubber measures is primarily taken from the latest draft of the livestock BREF, which contains a good level of data, reflecting the greater prevalence of air scrubbers in the sector in Europe[1] (EC, 2011). Manual oil spraying has also been assessed as a more cost effective alternative to scrubbers which would be more suited to small scale operations. This measure is primarily based on an academic paper from the Agricultural Engineers Digest (Zhang,Y., 1997) although oil spraying (which can also be automated) is also discussed in the BREF.

22.3.2 Air scrubbers – methodological approach

The two basic forms of scrubbers which have been assessed are acid air scrubbers and bioscrubbers, along with a number of combination scrubbers which generally have higher abatement efficiencies at slightly higher costs. Different technologies are also more suited to different installations and livestock; for example, bioscrubbers are less suitable for poultry due to the fact that poultry rearing operates on short rearing cycles, with a deep clean between cycles, and bioscrubbers are not as easy to turn off as acid scrubbers (EC, 2011). Bioscrubbers have therefore only been applied to emissions from pig housing, combined with acid scrubbers into one single scrubber measure for pig housing.

The data on abatement efficiency from air scrubbers in the literature is presented in terms of dust, PM10 and PM2.5. However, there are a number of data gaps. In order to fill in these gaps, missing data has been extrapolated between PM10 and PM2.5 based on the quoted air scrubber average removal efficiencies of 62-93% and 47-90% for PM10 and PM2.5 respectively. This gives a removal efficiency for PM2.5 which is on average 88% of the PM10 removal efficiency. This ratio is applied to:

- Single acid scrubber
- Bioscrubber
- Two step bioscrubber with water curtain
- 2 stage scrubber
- 3 stage scrubber with water, chemical scrubber and biofilter

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[1] These are currently included in a section titled ‘Techniques to consider in the determination of Best Available Techniques’ in this draft, as BAT has yet to be established. They are however potential BAT rather than ‘Emerging techniques’.

In the case of the three stage scrubber, EC (2011) references a removal efficiency of 94.8-97.8% for dust and 80% for PM10. On the basis that both this ratio and the average ratio of PM10 to PM2.5 abatement efficiencies are illustrative of the fact that scrubbers are more effective on the larger end of the spectrum of particulate matter than on the finer particulates, a similar scaling approach has been applied using this data to scale between dust and PM10 abatement efficiencies. The derived ratio for PM10 to dust is 83%, which is applied to the single bioscrubber data and the 2 step bioscrubber measure.

EC (2011) states that in the case of bioscrubbers, ‘air flow rates related to these systems are typically around 30 000m^3/h and have been reported up to 84 500 m^3/h.’ System durability is given as 10 years. It has not been possible to establish standard air flow rates for other variants of scrubber technologies, so the 30,000 m^3/h figure has been applied as an average across the range of scrubber technologies in order to work up costs, which are quoted on the basis of 1000 m^3/h modules. As the source applies to IPPC/IED permitted installations, it is assumed that the typical capacity quoted can be applied to IED threshold installations in the UK.

Uptake for scrubbers is modelled on the basis that these need to be fitted to closed as opposed to naturally ventilated buildings. EC (2011) states that the average operating life of livestock buildings is 20 years. However, discussions with the Environment Agency[2] have indicated that buildings in the sector in the UK can operate for up to 40 years, so we have adopted a slightly higher average of 25 years, giving an annual renewal rate of 4%. The EA has also indicated that current uptake of scrubbers is likely to be either minimal or non-existent. Potential uptake in IED installations by 2025 and 2030 is therefore calculated on the assumption that scrubbers can technically be fitted to all new buildings from 2015. The numbers of installations to which this rolling uptake is applied is based on 2007 Eurostat figures on the number of installations which fall above the IED size threshold (40,000 for broilers, 2,000 for fattening pigs and 750 for sows).

22.3.3 Pigs housed livestock emissions

Overview

Based on 2007 figures reported to Eurostat, the current portion of pigs in installations which fall under the IPPC permitting regime is around 47%. It is assumed that emissions are proportional to the number of heads. Scrubber measures are therefore considered applicable to 47% of emissions from this source, and oil spraying to the remaining 53%.

Bioscrubbers

With bioscrubbers, a biolayer that is formed on the surfaces of the packed material absorbs and reduces ammonia into nitrites and nitrates that in turn is reduced by microbes. Water circulation keeps the biolayer moist and the nutrients available for the microorganisms. The biofilter can be preceded by a simpler filtering stage to reduce dust

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[2] Telecon with Alison Holdsworth (07/06/12) and Nicola Barnfather (08/06/12).

and odour, which often is done by the ‘water curtain’. Bioscrubbers with water curtains are referred to as a ‘two-step bioscrubbers’. Ammonia reductions have been reported for at least 70 % and up to 85 % of the content in the treated air. The odour reduction varies between 28 % and 75 %. A removal of dust of around 60 % can be usually obtained, and can be raised to 95 %, especially with the use of a dedusting filtering stage (EC, 2011).

An investment of EUR 470 to EUR 720 is necessary for each 1000 m3/hour of capacity. The annual running costs vary between EUR 90 to EUR 110. The durability of the system is expected to be around 10 years (EC, 2011).

A 2 step bioscrubber measure has also been developed as a standalone measure for pig housed livestock emissions.

Combined single scrubber measure

In the case of chemical air scrubbers, the ventilation air is fed through a filter chemical scrubbing unit where an acid scrubbing liquid is trickled. Sulphuric acid is mostly used in this system and is automatically added to keep the circulating liquid within a set pH range (EC, 2011). Ammonia reductions of at least 85 % and up to 99 % of the content in the treated air are reported. The odour reduction efficacy varies between 30 % and 40 %. A removal of dust of around 60 % can usually be achieved, which can reach about 70 % and 94–96 % (winter and summer) if a dedusting neutral stage is applied. Costs were not reported in the same format as for other types of scrubbers, therefore in order to make them consistent across scrubber technologies, costs have been developed based on single bioscrubber costs, which have then been scaled using the average per head of livestock costs of pigs, from the draft BREF. The cost ratios between scrubber technologies are assumed to be equal for both pigs and poultry, as the same technologies are in use for both livestock.

Table A22.2 Scrubber costs per head of pig

Scrubber type	Capex (EUR)				Opex (EUR per year)			
	Weaner	farrowing sow	gestating sow	fattening pig	Weaner	farrowing sow	gestating sow	fattening pig
Biological	15	170	90	40	30	30	20	10
chemical 70%	10	105	60	30	2	20	15	8
chemical 95%	12	120	70	35	3.5	30	20	11
2 steps biological	16	170	100	50	4	35	23	12

Source: EC, 2011. The percentage reduction in the two differentiated chemical scrubber measures is based on ammonia reduction potential.

A combined single scrubber measure has been developed using average abatement efficiency and costs for bioscrubbers and acid air scrubbers.

Combination scrubbers

Two main types of combination scrubbers have been assessed based on data from the latest draft of the revised BREF: the two-stage scrubber of combined chemical wet scrubber and bioscrubber, and a three-stage scrubber of combined water scrubber, chemical wet scrubber and biofilter.

In the two-stage scrubber, ammonia reductions in the range of 70 to 96% can be achieved, along with odour reduction from 60 to 77% and total dust reduction from 85 to 98%. For modules with a capacity of 1,000 m^3/h, investment costs range between EUR 720 and 770, and annual running costs between EUR 120 and 140.

The three-stage scrubber combination consists of three filter walls. The first is a continuous water scrubber that removes part of the particulate matter and converts part of the ammonia into nitrate and nitrite by means of the microbial activity in the washing water. The second filter is continuously sprayed with sulphuric acid solution and removes part of the ammonia content and fine dust. The third step is a biofilter made of a column packed with root wood, which is frequently sprayed with water to keep it moist. Ranges for ammonia reduction were from 64% to 84% and for odour reduction were from 64% to 87.9%. The achievable dust removal is between 94.8% to 97.8%. For modules of a capacity of 1000 m^3/h, investment costs are between EUR 500 and 615, and annual running costs are between EUR 130 and 160.

Oil spraying

In the automated version discussed in the 2011 draft BREF, pure rapeseed oil is sprayed by nozzles inside the housing. Circulating dust particles are bound to the oil drops, and are collected in the bedding or litter. Costs are not presented, although reduction efficiencies of 50% and 75% are referenced for PM10 and PM2.5 respectively.

Further literature on costs associated with oil spraying are limited. However, an article has been identified by Yuanhui Zhang, an Associate Professor at the Department of Agricultural Engineering University of Illinois, which is based on a year controlled study in the Prairie Swine Center in Canada (Zhang,Y., 1997). The treatment consisted of sprinkling crude canola oil daily throughout the room in variable dosages that averaged 6 millilitres per square meter of floor area. On average, this treatment reduced modified respirable dust against the control room by 81% (defined as smaller than 5 microns diameter), and inhalable dust by 85%. For these improved conditions in an operation marketing 4,000 pigs per year, estimated costs were approximately $1.14 per pig marketed, in nominal prices. Of the total cost, 70% is for labour, whilst the backpack sprinkler used in this study cost approximately $120.

Table A22.3 Annual cost of sprinkling a 20,000 ft2 swine facility

Item	Cost
Backpack sprayer	$120
Oil, (660 gallons @ $2/gal)	$1,320
Labour: Person-hour to sprinkle, 360-hr, $8/hr	$2,880
Extra time for power wash, 30-hrs, $8/hr	$240
Total cost	$4,560
Cost per pig marketed	$1.14/pig marketed

Source: Zhang,Y., 1997

The costs have been adapted to apply to the UK. The capital cost for the backpack sprayer has been converted and adjusted for inflation. The labour costs have been recalculated based on the post October 1st 2012 minimum wage of £6.19 (Directgov, 2012) with an assumed uplift of 10% to represent the cost of employment. The operating costs have then been scaled to the average number of pigs on non-permitted farms, which is 1,254 according to 2007 figures reported to Eurostat, and then converted and adjusted for inflation.

It is recommended this measure is revisited when/if more appropriate cost data becomes available i.e. costs associated with an automated approach rather than the manual approach described above.

22.3.4 Broilers housed livestock emissions and other poultry housed livestock emissions

Overview

As a consistent approach has been taken for all sources, the preceding sections should be referred to in a first instance for general methodological approach and the costs and abatement efficiencies of the measures developed.

Based on 2007 figures reported to Eurostat, the current portion of broilers in installations which are subject to the IPPC permitting regime is around 92% (by number of heads). It is assumed that emissions are proportional to the number of heads. Scrubber measures are therefore considered in the context of 92% of emissions from this source, and oil spraying to the remaining 8%. In the case of other poultry housed livestock emissions (note, this excludes laying hens), no equivalent data from Eurostat was available within the timescales of this study. Therefore, assumptions on the number of poultry heads in installations which are subject to IPPC are based on Misselbrook et al (2010) which describes the development of the UK's ammonia emissions inventory. The proportion of duck and turkey heads assumed to be on IPPC farms is 35% and 43% respectively. As there are a greater number of turkey heads than ducks (Defra Farm Survey Statistics, 2012)[3], we have assumed a figure of 40% of other poultry heads, and subsequently emissions, could be subject to scrubbers with the remainder (60%) subject to oil spraying.

Scrubbers

The single scrubber measure assessed for poultry sources does not include bioscrubbers, as these systems can not be easily turned on and off, making them less suitable to poultry farms that apply all-in-all-out animal management. The cost ratios between scrubber technologies are assumed to be equal for both pigs and poultry, as the same technologies are in use for both livestock.

Oil spraying

The costings for oil spraying, which have been developed for housed pig emissions in non-permitted (i.e. smaller) installations, are applied to both poultry measures. Insofar as the operating costs in terms of labour costs (as a function of time required for spraying) and oil costs are based on installations with an average of 1,254 fattening pigs, costs are potentially a slight overestimate in the case of broiler installations, where the average number of broilers in non-permitted farms is 8,810. This is based on a calculated ratio of around 7:1 between the broiler head and fattening pig head averages, compared against an implicit emission ratio of 20:1 based on the IED thresholds. No equivalent data for other poultry farm average sizes was available so this was assumed to be the same as for broilers i.e. 8,810.

A22.4 Summary of measures and costs

Table A22.3 summarises the estimated cost of each abatement technology for the intensive livestock sector. The costs in the summary table are based on the average cost of each abatement technology. The range of costs were summarised in Section 1.3. Table A22.4 presents the reduction efficiency of the abatement measures and the associated reduction in emissions.

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[3] Available from http://www.defra.gov.uk/statistics/files/defra-stats-foodfarm-landuselivestock-june-statsrelease-uk-120530.pdf

Table A22.4 Summary of beyond BAU abatement measures for the intensive livestock sector for 2025 and 2030

Abatement measure	Future uptake of measure (%)		Operating life (years)	Capital Costs (£k, 2011 prices)		Annual operating costs (£k, 2011 prices)		Total annualised costs (£kpa, 2011 prices)	
	2025	2030		2025	2030	2025	2030	2025	2030
Oil spraying – broilers	8%	8%	10	23	23	290	290	292	292
Oil spraying – other poultry	60%	60%	10	921	921	11,570	11,570	11,681	11,681
Oil spraying – pigs	53%	53%	10	581	581	7,299	7,299	7,369	7,369
Single chemical scrubber – broilers	37%	55%	10	10,428	13,425	1,617	2,081	2,871	3,695
Single chemical scrubber – other poultry	40%	40%	10	3,895	5,842	604	1,593	1,072	2,296
Single scrubber – pigs	19%	28%	10	22,398	33,598	3,297	4,945	5,990	8,985
Two stage scrubber – broilers	37%	55%	10	13,989	20,984	2,441	3,662	4,123	6,185
Two stage scrubber – pigs	19%	28%	10	27,747	41,620	4,842	7,263	8,178	12,267
Two step biological scrubber – pigs	19%	28%	10	27,542	41,313	3,062	5,352	6,374	10,320
Three stage scrubber – broilers	37%	55%	10	10,468	15,703	2,723	4,084	3,981	5,972
Three stage scrubber – pigs	19%	28%	10	20,764	31,145	5,400	8,101	7,897	11,846

Note: The costs presented here are the average costs for each abatement measure (in case a measure was given a range of costs. A discount rate of 3.5% is considered in the analysis.

Table A22.5 Summary of beyond BAU abatement measures efficiency for the intensive livestock sector

Abatement measure	Emission reduction efficiency (%)						Reduction in 2025 emissions (kt)						Reduction in 2030 emissions (kt)					
	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3
Oil spraying – broilers			81.0%	81.0%					0.07	0.40					0.07	0.40		
Oil spraying – other poultry			81.0%	81.0%					0.17	0.96					0.17	0.96		
Oil spraying – pigs			81.0%	81.0%					0.09	0.50					0.09	0.50		
Single chemical scrubber – broilers			68.5%	77.5%		90.0%			0.32	1.72					0.49	2.58		
Single chemical scrubber – other poultry			68.5%	77.5%		90.0%			0.12	0.62					0.12	0.62		
Single scrubber – pigs			68.5%	77.5%		90.0%			0.03	0.17					0.05	0.26		
Two stage scrubber – broilers			67.2%	76.0%		70.3%			0.32	1.69					0.49	2.53		
Two stage scrubber – pigs			67.2%	76.0%		70.3%			0.03	0.17					0.05	0.25		
Two step biological scrubber – pigs			69.8%	78.9%		84.0%			0.03	0.17					0.05	0.26		
Three stage scrubber – broilers			70.7%	80.0%		74.0%			0.32	1.78					0.49	2.67		
Three stage scrubber – pigs			70.7%	80.0%		74.0%			0.03	0.18					0.05	0.27		

Note: No reduction in emissions has been estimated for ammonia as it was not within the scope of this study.

A22.5 References

1. Directgov, 2012. Employment, The National Wage Minimum Rates, Available from http://www.direct.gov.uk/en/employment/employees/thenationalminimumwage/dg_10027201 [Accessed 15/06/12]

2. EC, 2011. Integrated Pollution Prevention and Control (IPPC) Reference Document on Best Available Techniques for the Intensive Rearing of Poultry and Pigs, Draft 1- March 2011

3. EMEP/EEA, 2010. EMEP/EEA emission inventory guidebook 2009, updated June 2010. Available from: http://www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009/part-b-sectoral-guidance-chapters/4-agriculture/4-b/4-b-animal-husbandry-and-manure-management.pdf/at_download/file

4. Environment Agency, 2011. EPR 6.09 Sector Guidance Note, How to comply with your environmental permit for intensive farming Appendix 11 Assessing dust control measures on intensive poultry installations, Version 1, March 2011

5. Telephone communication, Alison Holdsworth, Environment Agency (07/06/12)

6. Telephone communication, Nicola Barnfather, Environment Agency (08/06/12)

7. Misselbrook, T.H.; Chadwick, D.R.; Gilhespy, S.L.; Chambers, B.J.; Smith, K.A.; Williams, J.; Dragosits, U.. 2010 Inventory of ammonia emissions from UK agriculture 2009. North Wyke Research, 34pp. (DEFRA Contract: AC0112, CEH Project Number: C03642) (Unpublished)

A23. Contents

A13.Animal Carcasses (Incineration)

A13.1 Sector profile

Animal carcass incinerators range vastly in size and nature. Small incinerators are by far the most numerous, which are widely found on farms, and as pet incinerators. There were estimated to be approximately 2,600 of these low capacity installations in the UK in 2001. There was one large operational animal incineration site listed in *Incineration Inputs and Capacity* by Environment Agency (2010), which had a capacity of 1,800 tonnes per year. Defra (2010a; 2010b; 2010c) also lists the number of installations where the A2 and Part B guidance notes are used, and lists eight A2 sites and 20 Part B sites in the UK. The larger incinerators are often used at veterinary clinics.

The incineration process gives rise to particulate emissions, which account for approximately 1% of the UK PM2.5 total. Minor amounts of NOx, SO_2 and VOCs are also emitted, but animal carcasses incineration is not a significant source of these emissions compared to the rest of the UK sources.

A13.2 Business as usual policies and abatement measures

Low capacity animal carcass incinerators are built to take an incineration capacity below the regulated rate. These units are not regulated, so no emission limits are prescribed for these incinerators. Larger units are regulated by either the Integrated Pollution Prevention and Control (IPPC) or Pollution Prevention and Control (PPC) system, depending on the incineration rates below.

- Low capacity incinerators (<50 kg/hr) – no specific limits given
- Small installations (500kg to 1 tonne/hr, but <10 tonnes per day) – Part B regulation
- Large installations (<1 tonne/hr, but >10 tonnes/day) – A2 regulation
- Greater capacity than 1 tonne/hr – A1 regulation

Part B sites have an emission limit 100 mg/m^3 for total particulate matter, and the larger A1 and A2 sites are restricted to 10 mg/m^3. Unabated PM emissions would be greater than both these emission levels, so it is assumed that filtration systems are in place for the small and large incinerators to meet their permit requirements. The low capacity incinerators, which are not regulated, are assumed to have no abatement in place. There are no known planned changes to this.

Animal carcasses are excluded from the scope of the Waste Incineration Directive (WID), so installations are excluded if this is the only incineration material. If any materials covered by the WID are also burned, then the WID requirements would apply.

A13.3 Beyond business as usual potential abatement measures

13.3.1 Costs to Meet Future Regulation

PM10 and PM2.5

No specific measures for reducing PM emissions were identified in the BREF (EC, 2005) or the literature review. However, low capacity incinerators have the potential to reduce emissions to similar levels as larger regulated sites using a scrubber. The BREF reports average dust emissions with limited scrubbing to range from 14 – 180 mg/m^3, so an average of 97 mg/m^3 was used. The larger regulated sites have emissions limits of 10 mg/m^3, and the abatement efficiency to reduce emissions to this level is 90%. It is estimated that 80% of projected emissions are from unregulated sources, based on AEA specification that most of the sector emissions are from unregulated sources.

An average cost estimate was given for £$_{1999}$ 175,000 per site to meet similar levels as regulated sites, which for 2600 sites gives a total capital cost of £$_{1999}$ 455 million (Environment Agency, 2001). No ongoing operating costs were included, so an estimate based on the average ratio of operational expense to capital expense from the previous MPMD 2020 analysis for all measures was used, of 2.3%. This gave a figure of £$_{1999}$ 10.5 million for the estimated operational expense.

A13.4 Summary of measures and costs

Table 23.1 summarises the estimated cost of each abatement technology for animal incineration sector. The costs in the summary table are based on the average cost of each abatement technology. The range of costs were summarised in Section 1.3 dust abatement measures. Table 23.2 presents the reduction efficiency of the abatement measures and the associated reduction in emissions.

Table A23.1 Summary of beyond BAU abatement measures for the Animal Incineration sector for 2025 and 2030 [1]

Abatement measure	Future uptake of measure (%)		Operating life (years)	Capital Costs (£k, 2011 prices)		Annual operating costs (£k, 2011 prices)		Total annualised costs (£kpa, 2011 prices)	
	2025	2030		2025	2030	2025	2030	2025	2030
Extension of regulation	80%	80%	15	647,013	647,013	14,881	14,881	71,058	71,058

Note 1: The costs presented here are the average costs for each abatement measure (in case a measure was given a range of costs. A discount rate of 3.5% is considered in the analysis.

Table A23.2 Summary of beyond BAU abatement measures efficiency for animal incineration sector

Abatement measure	Emission reduction efficiency (%)						Reduction in 2025 emissions (kt)						Reduction in 2030 emissions (kt)					
	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3	NOx	SO_2	$PM_{2.5}$	PM_{10}	VOC	NH_3
Extension of regulation			89.7%	89.7%					0.22	0.22					0.22	0.22		

A13.5 References

1. AEA (August 2002) “Atmospheric Emissions from Small Carcass Incinerators” – A report for Defra, AEA Technology Environment

2. EC (May 2005) “Integrated Pollution Prevention and Control Reference Document on Best Available Techniques in the Slaughterhouses and Animal By-products Industries”

3. Defra (July 2005) “Sector Guidance Note IPPC SG10 Integrated Pollution Prevention and Control (IPPC) Secretary of State's Guidance for A2 animal carcass incineration with capacity of less than 1 tonne per hour”

4. Defra (2010a) “Installations where PG note relates to primary activity” http://www.defra.gov.uk/industrial-emissions/las-regulations/guidance/

5. Defra (2010b) “Installations where PG note relates to secondary activity”

6. Defra (2010c) “Installations where SG note relates to primary activity”

7. Defra (March 2012) “Process Guidance Note 5/03(12) Statutory Guidance for Animal Carcass Incineration”

8. Environment Agency (2001) “Towards Sustainable Agricultural Waste Management”

9. Environment Agency (2011) “England and Wales - Incineration Inputs and Capacity 2010” http://www.environment-agency.gov.uk/research/library/data/132647.aspx