EMISSION FACTORS FOR DOMESTIC SOLID FUELS

Work Package 2 Report

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1. EXECUTIVE SUMMARY

1.1 Introduction

This is the Work Package 2 Report for the project “Emission Factors for Domestic Solid Fuels”. The project is being undertaken by Ricardo Energy and Environment (Ricardo), Kiwa Gastec (Kiwa), Environmental Compliance Ltd (ECL), University of Manchester and University of Leeds for the United Kingdom Department for Environment, Food and Rural Affairs (Defra).

Work Package 2 concerns the development of emission factors for the combustion of coal, anthracite, Manufactured Solid Fuels (MSFs) and coffee logs in a range of appliances that can be commonly found in domestic residences in the UK, at the time of writing.

This report contains background information about the project team, scope of work and methodology. It includes detailed information about the fuels and appliances, and results of the test programme which have been used to develop the emission factors. Within the report the authors outline the challenges and uncertainties associated with the final emission factors.

The emission factors developed through this project are intended to be used directly in the UK National Atmospheric Emissions Inventory, which fulfils reporting requirements under the National Emissions Ceiling Directive (NECD), transposed into UK law as the National Emissions Ceiling Regulations (NECR); the United Nations Economic Commission for Europe (UNECE)’s Convention on Long Range Transboundary Air Pollution (CLRTAP).

In addition to fulfilling the national and international reporting requirements, the NAEI provides emissions data for a wide range of other uses including providing policy makers and the public with an understanding of the key polluting sources, how these sources have varied over time and how they are likely to contribute to pollution in the future.

This report should be read in conjunction with the project Inception Report, Test Protocol and Work Package 1 report, which provide full detail on the methodologies employed and results to date.

1.2 Governance

A Steering Group has been set up by Defra to provide expert advice around domestic solid combustion, emissions measurements, and emissions factors calculations; to review progress and outcomes from the emissions factors project. The Steering Group are required to review and approve results, reports, model(s), calculations and other project outputs and challenge assumptions. The Steering Group has convened several times during this study and has given approval to proceed at key stages of the project:

1. Approval of the Test Protocol
2. Approval to proceed to the main test programme following review of results from the Round Robin testing
3. Approval of the outputs of the WP1 test programme and emission factors
4. Approval of the outputs of the WP2 test programme and emission factors

Selected outputs of WP2 will be presented to the UK’s Air Quality Inventory Steering Group (AQISG), a separate group with remit to govern the scientific development of the NAEI. The AQISG will be asked to provide approval for use in the NAEI 2023 (to be submitted spring 2025).

1.3 Fuel

Work Package 1 focussed on wood fuels, for Work Package 2 a range of mineral and manufactured solid fuels (MSF) were selected, based on availability and representativeness. These were:

1. House coal trebles. Supply of this fuel is now prohibited in England and is not authorised for use in smoke control areas.
2. Anthracite small nuts, approved under the generic authorisation for smokeless fuels.

3. "Heat Approved" Manufactured Solid Fuel. This is a HETAS-approved smokeless and low sulphur fuel.
4. "Superheat" Manufactured Solid Fuel. Supply of this fuel is now prohibited in England. This is a non-approved, higher sulphur petcoke based fuel.
5. Biobean coffee logs for wood burners and multifuel stoves.

Fuel samples were independently analysed, and results are presented in the appendices.

1.4 Test cycle/burn cycle

The project test cycle considered emissions during ignition, steady operation including refuels, and shutdown. A full description is given in the test protocol and is summarised below. The typical batch mass of fuel varies depending on the stove and fuel under test as mineral and MSF require primary air (through the grate) and different grate sizes require different loads. Coffee logs were tested as two logs per burn.

- Fuel is weighed out for the test and screened to ensure that the fuel size is uniform removing large or broken pieces. For Coffee logs two are selected for the ignition phase.
- For ignition the total mass of kindling material was limited at 1/3 of the total batch mass.
- The total mass of starting aids (firelighter) was limited at 3% of the total batch mass. Firelighters were placed in the centre of the kindling. A kerosene-based firelighter was used for all ignition batches.

<u>Steady operation</u>

The operation step is the phase where the appliance is hot and will most closely align with standard test methods for domestic solid fuel heating appliances. In this step the appliance was allowed to run and burn down fuel in the fuel bed. The fuel bed was refuelled once for mineral and MSF and twice for coffee logs, refuelling when the flames have gone out. A standardised refuel procedure is described in the test protocol.

<u>Shutdown</u>

The shutdown step in the test cycle is the period where the final batch is allowed to burn out completely. The start of shutdown was defined as when the flames go out.

Typical durations for each phase are:

- Start-up 1 hour 30 minutes.
- Normal operation 1 hour 30 minutes.
- Shutdown 1 hour.

1.5 Measurements

Measurements for the main test programme were taken by Kiwa and ECL at the Kiwa laboratory. A custom-made test rig was used to house the appliances, sampling equipment and analysers.

The test programme is based on measurements on **three** test cycles for each fuel and appliance combination. Note that some measurements may be taken over all phases of a test cycle and others may be collected separately during start-up, shutdown and a single operating step.

Repeat testing allowed the uncertainty in the measurements to be reported and the interval and confidence level to be expressed. For this work a normal distribution will be used to assess the uncertainty and the result expressed to a 95% confidence interval. Three tests are the minimum required to complete this assessment.

The following pollutants were measured:

Table 1-1 Pollutants measured in Work Package 2

Measurement	Measurement location	Comments
CO CO_2 TOC/HC NOx	Appliance outlet	Continuous measurement, unweighted CO and O_2 used to standardise integrated samples. Weighted data used to standardise continuous measurements. NOx data used in preference to dilution tunnel data.
NOx CO CO_2 SO_2 TOC/HC	Dilution tunnel	Continuous measurements, unweighted CO data used to establish dilution ratio for integrated samples. Weighted CO data used to establish dilution ratio for continuous measurements. NOx and SO_2 not used (close to LoD and/or variable).
PM	Appliance outlet	Heated filter measurement, integrated samples for alternate phases of burn cycle.
PM	Dilution tunnel	Heated filter measurement, integrated samples for alternate phases of burn cycle.
Dioxins & Furans PAH	Dilution tunnel	Integrated sample collected over entire burn cycle (combined sample).
Heavy Metals	Dilution tunnel	Integrated sample collected over entire burn cycle (combined sample).
PM PM_{10}, $PM_{2.5}$, PM_1	Dilution tunnel	Impactor measurement, integrated samples for alternate phases of burn cycle.
Black carbon	Dilution tunnel	Integrated samples collected over short periods in alternate phases of burn cycle. Analysed for EC and OC. Single sample for each fuel, appliance and test phase.
Condensable PM	By calculation	Difference between heated filter (or particle size) measurements at dilution tunnel and appliance outlet.

1.6 Appliances

Three stoves and an open fire have been tested during Work Package 1 and 2, to represent the installed base in the UK and to capture the significant developments in stove performance over the years. The categories and appliances tested were:

1. Open fire - **Parkray Paragon inset open fire**
2. Pre 2000 closed stove - **Hunter Oakwood**
3. 2000-2009 closed stove - **Stovax / Dovre Model Dovre 500MRF**
4. Very efficient modern stove (clearSkies level 2 or above) - **Charnwood Model: C4**

It was not possible to test anthracite on the open fire due to difficulties keeping the fuel alight. A mineral fuel variant of the Charnwood C4 was used for Work Package 2.

1.7 Quality and Uncertainty

An independent audit has been carried out during Work Package 2 to assess compliance with the agreed test protocol and measurement methods. This has provided assurance that the test protocol and measurement methods have been followed and has identified improvements which have since been implemented.

The uncertainty in the final emission factors comprises a range of contributing elements including:

- Representativeness of the appliances
- Variation in fuels
- Variation in operation
- Measurement – include measurement method, sampling protocol, analysis LoD (Limit of Detection), calibration/reference materials
- Data handling – data acquisition, storage and handling – the processes to work up the measured data into the final emission factors.

These are discussed in Chapter 5.

1.8 Emission Factor Development

The measurement programme provided:

- continuously monitored emission concentration data throughout the different phases of the burning cycle for some gaseous measurements (CO, CO_2, O_2, NOx, SO_2, TOC),
- an integrated concentration measurement for (PCDD/F, PAH and heavy metals) over the whole burn cycle,
- integrated PM-related concentrations measurements for alternate phases of the burning cycle (ignition, 2nd operation/refuel and burnout phases).

The calculation of emission factors for each appliance and fuel combination from the emission concentration data reported by the test houses required several calculation stages, discussed in Chapter 6.

Emission factors have been developed for use in the NAEI for coal, anthracite and manufactured solid (mineral) fuels for the four appliance types for PM, $PM_{2.5}$, PM_{10}, NOx, SO_2, CO, NMVOC, PAH, PCDD/F. At the time of writing this report, these emission factors have not yet been approved by the Air Quality Inventory Steering Group (AQISG), their approval will be sought before use of the new emission factors is implemented in the NAEI.

In addition, emission factors have been developed for coffee logs but cannot be adopted by the NAEI as activity data are not available. Condensable PM emission factors have also been determined for all fuels (these are not currently applied in the NAEI as total filterable+condensable emissions are reported).

Black Carbon emission factors have also been developed in the measurement programme but are for a more limited dataset, with only one measurement taken for each appliance-fuel combination in each phase of the burn cycle (rather than three repeat measurements). In Work Package 3, three repeat measurements will be made for black carbon. This will allow verification of the data collected so far, and the WP2 data will be combined with the WP3 data to produce a black carbon emission factor for each category of appliance.

Heavy metal emission factor measurements indicated some anomalous data for certain metals which have been excluded from the data. The reported emission factors will be considered with further measurements for these pollutants undertaken in Work Package 3.

In general, although substantial changes can be seen for emission estimates from coal, anthracite and manufactured solid fuels, the impact of changes on UK national emissions is generally small. However, the new emission factors for PAH including Benzo(a)pyrene and PCDD/F would result in a significant reduction in national emissions.

The proposed country-specific emission factors are considered to be an improvement on current emission factors used by the NAEI because they:

- Better represent UK operating practise with respect to burn duration, number of refuels, fuel load, draught and the types of solid mineral fuels used in the UK.
- Are based on three replicate test cycles.
- Better represents appliances used in the UK.
- Are based on tests for the same appliance and the same test cycles for measured pollutants.
- Provide data measured by accredited test houses using test approaches that are consistent with EN and CEN/TS approaches for emission measurement.

It is notable that for the modern Ecodesign appliance using mineral fuels that there are higher emission factors for CO, PM and TOC/OGC (which have emission limits in the Ecodesign Regulation) and PCDD/F and PAH compared to the older appliances. Smaller differences in emission factors will be mitigated by higher energy efficiency for the modern appliance but elevated emission factors are often higher than could be offset by improved energy efficiency.

1.9 Recommendations

The following recommendations are made:

1. To include the emissions factors for PM, $PM_{2.5}$, PM_{10}, NOx, SO_2, CO, NMVOC, PAH, PCDD/F in the next submission of the NAEI (up to calendar year 2023, to be published in 2025).
2. To delay incorporation of the heavy metal and Black Carbon emission factors into the NAEI until completion and review of the Work Package 3 testing.
3. To investigate establishment of activity data to allow adoption of emission factors for coffee logs to be included in the NAEI if similar fuels are commercially available (the original manufacturer has ceased trading).
4. To consider similar testing programmes for to represent a wider range of appliances including new appliance types and emerging fuels.
5. To consider further testing on modern appliances to understand why emissions of certain pollutants appear to be elevated compared to older technologies.
6. To consider sensitivity testing of emission parameters to (for example) different lighting practises, inclusion of fines in fuel mix.
7. To consider alternatives to emission monitoring for determination of heavy metals (fuel and ash analysis).

We would like to dedicate this report to our dear friend and colleague, Prof Alan Williams, who passed away suddenly on 6th September 2023.

Alan was a lively and valued member of the research team on this project with nearly 70 years' experience in fuels, combustion and emissions. We will remember him as someone who was always sharp, always insightful, always prompting lively debate, and someone with a genuine thirst for enquiry in research. He is fondly remembered and sadly missed.

GLOSSARY

AQEG	Defra Air Quality Expert Group
AQISG	Air Quality Inventory Steering Group
BC	Black Carbon
BS	British Standard
CAS	Centre for Atmospheric Sciences (University of Manchester)
CEMS	Continuous Emission Monitoring Systems
CEN	European Standards organisation
CEN/TS	CEN Technical Specification
CLRTAP	Convention on Long-Range Transboundary Air Pollution
CO	Carbon Monoxide
Defra	Department for Environment, Food and Rural Affairs
DP	Differential Pressure
EC	Elemental Carbon (Black Carbon)
ECL	Environmental Compliance Limited
EEA	European Environment Agency
EF	Emission Factor
EFDSF	Emission Factors for Domestic Solid Fuels (this project)
EIG	Emission Inventory Guidebook
EMEP	European Monitoring and Evaluation Programme (of the UN Convention on long-range Transboundary Air Pollution)
EN	European Standard
EPA	Environmental Protection Agency (US)
FID	Flame Ionisation Detector
FTIR	Fourier Transform Infrared Spectroscopy
GC-MS	Gas Chromatography-Mass Spectrometry
GJ	Gigajoules
HEPA	High-Efficiency Particulate Air
HETAS	Heating Equipment Testing and Approval Scheme
ISO	International Organization for Standardization
I-TEQ	International Toxic Equivalent
IVOC	Intermediate Volatile Organic Compounds
LOD	Limit of Detection
MCERTS	Monitoring Certification Scheme
MCS	Microgeneration Certification Scheme
MJ	Megajoules
MSF	Manufactured Solid Fuels

MST	Manual Sampling Train
NAEI	National Atmospheric Emissions Inventory
NMVOC	Non-Methane Volatile Organic Compounds
NO	Nitrogen Oxide
NO_X	Nitrogen Oxides
NPL	National Physical Laboratory
OC	Organic Carbon
PAH	Polycyclic Aromatic Hydrocarbon
PCDD/F	Polychlorinated Dibenzo-p-Dioxins and Polychlorinated Dibenzofurans (also referred to simply as 'Dioxins')
PM	Particulate Matter
PTFE	Polytetrafluoroethylene
PVC	Polyvinyl Chloride
QA/QC	Quality Assurance/ Quality Control
SCAPE	School of Chemical and Process Engineering (University of Leeds)
SG	Steering group
SO_X	Sulfur Oxides
STP	Standard Temperature and Pressure
SVOC	Semi-volatile Organic Compounds
TB	Test Batch
TC	Total Carbon
TGA	Thermogravimetric Analysis
TOC	Total Organic Carbon
TPM	Total Particulate Matter
UKCA	UK Conformity Assessment
VOC	Volatile Organic Carbon
WP	Work Package

2. INTRODUCTION

2.1 BACKGROUND

This is the Work Package 2 Report for the project “Emission Factors for Domestic Solid Fuels”. The project is being undertaken by Ricardo Energy and Environment, Kiwa Gastec, Environmental Compliance Ltd, University of Manchester and University of Leeds for the United Kingdom Department for Environment, Food and Rural Affairs (Defra).

The project is to provide data for the National Atmospheric Emissions Inventory (NAEI) which is a business-critical model used by Defra for policy development and to report emissions of air pollutants under international statutory obligations. The NAEI estimates emissions across a range of sectors and sources including domestic (residential) fuel use for heating, cooking and leisure.

The overall aim of the project is to reduce the uncertainty in the NAEI emission estimates for domestic combustion through the development of UK-specific pollutant emission factors for solid fuels (wood, mineral fuels and manufactured briquettes). Residential burning is a ‘key category’ in the UK emission inventory for many pollutants, which means that it is a source which makes an important contribution to the emissions totals and trends. Key categories are those which, when summed up in descending order of magnitude, cumulatively add up to 80 % of the total level. The main contributions are from solid fuel use – for some pollutants solid fuel is the largest source.

The aim of the project is to develop emission factors for a range of pollutants emitted from burning the following solid fuels in selected domestic appliances:

- wood (for a range of moisture contents)
- house coal
- anthracite
- manufactured solid fuels (MSFs)
- coffee logs.

Work Package 2 concerns the development of emission factors for the combustion of coal, anthracite, MSFs and coffee logs in a range of appliances that can be commonly found in domestic residences in the UK, at the time of writing.

This report contains background information about the project team, scope of work and methodology. It includes detailed information about the fuels and appliances, and results of the test programme which have been used to develop the emission factors. Within the report the authors outline the challenges and uncertainties associated with the final emission factors.

2.2 AIMS AND OBJECTIVES

This project includes three technical work packages (WP1, WP2 and WP3) and a project management work package (WP4). WP1 is the “Measurement of emission factors for wood fuels” and ran from September 2021 to May 2022. The report of the WP1 work package has been published[1]. WP2 is the “Measurement of emissions factors for other domestic solid fuels - house coal, anthracite, Manufactured Solid Fuels (MSFs) and coffee logs”, carried out between May 2022 and October 2022. WP3 is an extension of WP1 and WP2, measuring emissions of the fuels in additional appliances, and at the time of writing the measurement programme for WP3 is not complete.

Work Package 2 - Measurement of emissions factors for other domestic solid fuels (house coal, anthracite, MSFs and coffee logs) included the following tasks and this report draws together the deliverables outlined below:

- Measurement of specified pollutants emissions (Deliverable 2.1)
- Provide compositional and proximate analysis of the fuels tested (Deliverable 2.2)

[1] Emission Factors for Domestic Solid Fuels Project - Work Package 1 Report available here : https://naei.beis.gov.uk/reports/reports?report_id=1133

- Emitted pollutants speciation and categorisation (Deliverable 2.3). The full suite of species measured is given below, and the measurement results have been used to develop aggregated emission factors for each category of pollutant. This is commensurate with the aggregated emission factors used in the NAEI.

  - ✓ Particulates
    - Total filterable particulate matter (including condensable fraction)
    - Particulate fractions PM_{10} / $PM_{2.5}$ / PM_1 (including condensable fraction)
    - Condensable PM fraction.

  - ✓ Polynuclear aromatic hydrocarbons (PAHs)
    - Anthanthrene
    - Benzo(a)anthracene
    - Benzo(a)pyrene
    - Benzo(b)fluoranthene
    - Benzo(b)napth(2,1-d)thiophene
    - Benzo(c)phenanthrene
    - Benzo(ghi)perylene
    - Benzo(k)fluoranthene
    - Cholanthrene
    - Chrysene
    - Cyclopenta (c,d)pyrene
    - Dibenzo(a,i)pyrene
    - Dibenzo(ah)anthracene
    - Fluoranthene
    - Indeno(1,2,3-cd)pyrene
    - Naphthalene

    Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(k)fluoranthene and Indeno(1,2,3-cd)pyrene are used for international reporting.

  - ✓ Polychlorinated dibenzo-p-dioxins (PCDDs) and dibenzofurans (PCDFs)

    We monitored the following tetra, penta, hexa and hepta chlorinated dibenzo dioxin and furan congeners which have toxic equivalence factors.
    - 2378-TCDD
    - 12378-PCDD
    - 123478-HxCDD
    - 123678-HxCDD
    - 123789-HxCDD
    - 1234678-HpCDD
    - 2378-TCDF
    - 12378-PCDF
    - 23478-PCDF
    - 123478-HxCDF
    - 123678-HxCDF
    - 234678-HxCDF
    - 123789-HxCDF
    - 1234678-HpCDF
    - 1234789-HpCD

    *Note the **total** (expressed as a toxic equivalence) is required for international reporting.*

  - ✓ Heavy Metals:
    - Arsenic (As)
    - cadmium (Cd)
    - cobalt (Co)
    - chromium (Cr)
    - copper (Cu)

- manganese (Mn)
- nickel (Ni)
- lead (Pb)
- antimony (Sb)
- selenium (Se)
- thallium (Tl)
- vanadium (V)
- mercury (Hg)
- zinc (Zn)

Lead, cadmium and mercury are 'priority' metals for international reporting.

- ✓ Black carbon refers to only condensed phase species and will include the IVOC and SVOC that is condensable on the filter media taken from the cooled dilution tunnel sampling point.
- ✓ SO_2 **,** NOx, CO, TOC

- Emissions Factors development (Deliverable 2.4)

The scope of work is summarised in Table 2-1, below.

Table 2-1 : Summary of Technical Work Package 2 specification

WP	Item	Requirement		
2	***Measurement of emissions factors for other domestic solid fuels - house coal, anthracite, MSFs and coffee logs.***			
2.1	Measurements	Fuel	Appliance	Pollutant
		House coal Anthracite MSF1 (high smoke/sulphur) MSF2 (low smoke/sulphur) Coffee logs	3-4 appliances (open fire and stoves)	$PM_{2.5}$ filterable and condensable Polycyclic aromatic hydrocarbons (PAHs)/ Benzo[a]pyrene (B[a]P) Polychlorinated dibenzo-p-dioxins (PCDDs) and dibenzofurans (PCDFs) SO_2 Black Carbon Heavy metals: As, Se, Hg, Pb
2.2	Fuel analysis	Compositional and proximate analysis of fuels tested		
2.3	Emission speciation	Speciation and categorisation of emitted pollutants		
2.4	Develop Emission factors	For pollutants of interest		
Other	-	Rationale for MSFs chosen		

A full description of the scope of work and approach is given in the Inception Plan[2], which was presented to the Steering Group and Defra at the project outset. Details of fuels and appliances are provided at Section 3 and Section 4 respectively.

2.3 TEAM

The project team includes the current National Atmospheric Emissions Inventory (NAEI) Agency (Ricardo), and the project team fully understand the existing model and the needs of the Inventory

[2] Emission Factors for Domestic Solid Fuels: Deliverable 5.1 - Inception Plan, Ref: ED 14880, Issue 1, 25/8/21

Agency for incorporating new information. Several members of the Ricardo team are also part of the NAEI project team and have detailed understanding of the NAEI, residential combustion models and international best practise for emission inventories.

Ricardo is an energy and environmental consultancy, providing overall management and technical leadership of the programme of work.

Kiwa Gastec have led the procurement, set up and testing of emissions from the range of appliances covered by this work. Kiwa holds accreditations for laboratory testing of solid fuels and appliances and measurement of smoke emissions, for product certification under the MCS scheme of biomass appliances and for UKCA Approved Body activities under the Construction Product Regulation for solid fuel heating appliances.

Environmental Compliance Limited (ECL) is an accredited emissions monitoring test house which has carried out testing of PCDDs/PCDFs/PAHs, Heavy metals, Acid Gases, Volatile Organic Compounds and combustion gases in Work Package 2.

The **University of Leeds** School of Chemical and Process Engineering (SCAPE) has provided expert advice to the project team through the project Steering Group and verification of the test protocol through participation in Round Robin testing during the initial stages of the project. It has world-class facilities for the characterisation of solid fuels, including a fully instrumented, biomass heating stove test facility (gas analysis, temperature measurements, burning rates, flow rates, total particulate, particle size, VOC all in situ; PAH ex situ).

The Centre for Atmospheric Sciences (CAS) at the **University of Manchester** has also provided expert advice and test protocol verification through participation in Round Robin testing. Their state-of-the-art laboratories have been used to provide further detailed analysis of the black carbon and condensable fractions of the emitted pollutants.

2.4 STEERING GROUP

2.4.1 Role and membership

A Steering Group has been set up by Defra to provide expert advice around domestic solid combustion, emissions measurements, and emissions factors calculations; to review progress and outcomes from the emissions factors project. The Steering Group are required to review and approve results, reports, model(s), calculations and other project outputs and challenge assumptions. The project Steering Group will advise the NAEI Air Quality Inventory Steering Group (AQISG) on whether to adopt the new emission factors into the NAEI.

Defra's Emission Factors for Domestic Solid Fuels Steering Group includes representatives from the following organisations:

- Defra Air Quality and Industrial Emissions team
- Department for Energy Security and Net Zero (DESNZ)
- Defra Air Quality Expert Group (AQEG)
- Team representatives from the Supplier (Ricardo)
- Supplier's sub-contractors (University of Manchester, University of Leeds, Kiwa Gastec, Environmental Compliance Limited)
- Experts in domestic combustion, appliance testing and air quality science, including HETAS, National Physical Laboratory and Aarhus University.

2.4.2 Terms of Reference

The Emissions Factors for Domestic Solid Fuels Steering Group (EFDSF SG) has been established to:

- Provide expert advice around domestic solid combustion, emission measurements and emission factors calculations.
- Review progress and outcomes from the emission factors for domestic solid fuels project.
- Fulfil a role in steering and/or advising on the delivery of the project relevant to members' expertise - review and approve results, reports, model(s), calculations and other project outputs and challenge assumptions.
- Recommend the incorporation of these factors into the NAEI by working with the Air Quality Inventory Steering Group (AQISG) (run separately to this project). The final decision on whether to adopt these factors into the NAEI will be made by the AQISG.

2.4.3 Steering Group Meetings

The first Steering Group meeting and Technical Workshop was held on the 2nd September 2021 to present the project Inception Plan, Gantt chart and technical approach.

A second Steering Group meeting was held on 25th November 2021, at which the draft test protocol was discussed and views from the expert members sought. These were incorporated into the test protocol, which was approved by the Steering Group, along with the appliances and fuels to be included in testing, in December 2021.

The third Steering Group meeting was held on the 16th February 2022 to present and discuss the results of an initial Round Robin test programme. Following circulation of the test results, approval was given for the project to proceed to the main programme of testing.

A fourth Steering Group meeting took place on 7th July 2022 to discuss potential issues in the setup of the filter in the DIN+ which could potentially cause a bypass of particulate matter. This is discussed in detail in the Work Package 1 report.[3]

A fifth meeting was held on 12th September 2022, to examine the results of the WP1 main test programme and the developed emission factors. Following this meeting the Steering Group approved the outputs of the WP1 test programme and emission factors (with some exceptions), and these have since been presented to the UK's Air Quality Inventory Steering Group (AQISG), a separate group with remit to govern the scientific development of the NAEI. In November 2022 the AQISG approved the use of the new emission factors in the next annual NAEI compilation cycle 'NAEI 21', which includes annual emissions datasets up to 2021 and were published in Spring 2023 at https://naei.beis.gov.uk/.

An exceptional sixth meeting took place on 14th December 2022 to discuss issues relating to the measurement of particulate matter in WP1, and the Steering Group set out its approval of a proposed change to the sampling method, to include an o-ring seal in the filter housing.

The seventh meeting of the Steering Group was held on 27th February 2023, to examine the results of the WP2 test programme and the developed emission factors.

An eighth Steering Group meeting was held on 27 July 2023 to discuss outcome of PM measurement comparisons and proposals for dealing with (WP1) measurement issues. Also discussed proposed Blue Angel stove for WP3.

This report is provided as evidence, and contains further detail and explanation of methods, analysis of data and a review of the newly developed emission factors for WP2.

2.5 RELATED REPORTS

This report should be considered alongside the project Inception Plan[4], which outlines the scope of work and general approach, and the project Test Protocol[5], which is a detailed document stating the methodologies which have been used in the Work Package 2 test programme. The reader may also refer to the WP1 report, which describes the Round Robin testing at the programme outset, some modifications to the test methodologies after the initial development of the test protocol, and the results from WP1.

[3] Emission Factors for Domestic Solid Fuels: Work Package 1 Report, Ref ED14880, Final v1, 08/06/23

[4] Emission Factors for Domestic Solid Fuels: Deliverable 5.1 - Inception Plan, Ref: ED 14880, Issue 1, 25/8/21

[5] Emission Factors for Domestic Solid Fuels: Deliverable 1.1 – Test Protocol, Ref: ED 14880, Issue 1, 11/2/22

3. FUEL

Mineral fuels and manufactured fuels tend to have low variability in composition, moisture content and dimensions compared to wood fuels. They do however present more variability than refined liquid and gaseous fuels. Due to this, the variability of the fuel is more easily managed than the wood fuels used in Work Package 1. All fuels were stored in a secure storage bin within the testing laboratory, with consistent humidity and temperature. Most of the manufactured fuels are supplied in sealed plastic bags, which prevent moisture ingress during transport and storage.

Table 3-1 Fuel analysis results summary (as received basis)

Component	Units	MSF2 Heat Approved	MSF1 Superheat	Coal	Anthracite	Coffee logs
CV, net	MJ/kg	24.995	28.007	26.273	32.591	18.26
Moisture	% m/m	20.2	7.0	10.3	1.9	8.3
Ash	% m/m	3.8	4.6	1.3	3.6	0.8
C	% m/m	63.90	73.40	68.10	88.10	47.20
H	% m/m	3.13	3.93	4.71	3.62	6.02
N	% m/m	1.05	1.16	1.11	1.03	1.45
S	% m/m	1.36	2.35	0.18	0.75	0.04
O (by diff)	% m/m	6.56	7.56	14.30	1.00	36.19
Volatile matter (VM)	% m/m	14.2	22.2	39.9	6.6	74.6
Fixed Carbon (by diff)	% m/m	61.8	66.2	48.5	87.9	16.3
Calculated dry flue gas volume, 0% O_2	m^3/GJ (0°C, 101.3 kPa, net heat input)	249	259	255	264	248

3.1 HOUSE COAL

Figure 3-1 House coal trebles

Coal used was the CPL Premium House coal trebles, supplied in 25 kg plastic bags. This fuel is not authorised for use in smoke control areas. This fuel was supplied directly by CPL.

This type of fuel was, until recently, widely available at retail points such as DIY stores, petrol stations and garden centres. However, its sale in England for domestic uses has been prohibited since May 2023 under the Air Quality (Domestic Solid Fuels Standards) (England) Regulations 2020.

There is a wide range of coal lump sizes. Pieces weighing 60 – 80 g were selected from each bag. This results in 1/3 of the bagged fuel remaining unused.

The sulphur content of coal is very low at 0.2%, second only to the coffee logs. Volatile matter content is relatively high at 39.9% (44.5% on a dry basis), and the moisture content at 10.3%.

3.2 ANTHRACITE

Figure 3-2 Anthracite small nuts

Anthracite sourced was the GLO-PAK Anthracite Small Nuts. This is advertised as a naturally smokeless fuel and is approved for use in smoke control areas under the generic authorisation for smokeless fuels.

Volatile matter in this fuel is significantly lower than all other fuels tested at 6.6% (6.7% on a dry basis). The net and gross calorific values are higher than for all other fuels.

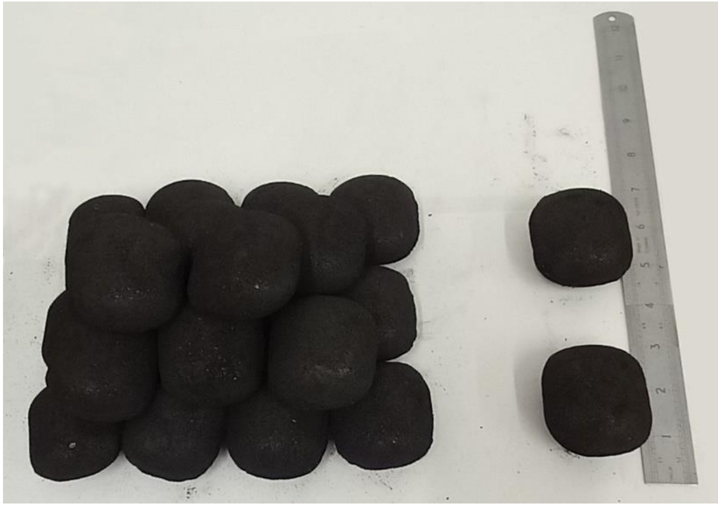
Anthracite proved difficult to light compared to other fuels. Significantly more heat had to be supplied by kindling and firelighters during the ignition phase. The amount of fuel itself was also increased to cover the entire fuel grate. Once ignited, this fuel burned slowly, releasing heat over a long time. Some firelighters had to be added on refuel to maintain the flame.

There is a large variation in the anthracite nut size. Pieces weighing 40-60g were selected from each bag of anthracite. This results in 1/4 of the bagged fuel remaining unused.

3.3 MANUFACTURED SOLID FUELS

Heat Approved (MSF2)

Figure 3-3 Heat Approved ovoids



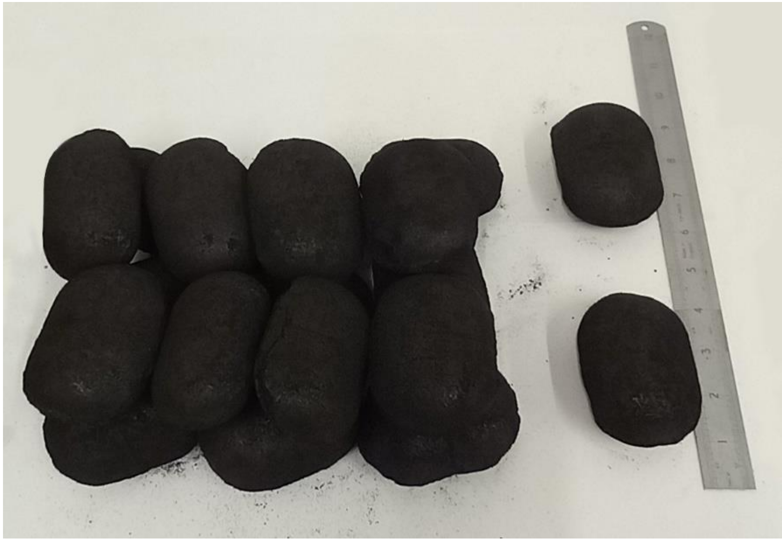
This is a HETAS approved smokeless (<5g/hr) and low sulphur (<2%) fuel. Heat Approved fuel was supplied by CPL directly. Heat Approved fuel was supplied in sealed 25kg plastic bags.

The small ovoid/pillow shapes are very uniform at approx. 1.5" x 1.5" with a thickness of 1".

Total moisture of this sample was measured at 20.2%, which is very high compared to other fuels tested.

Superheat (MSF1)

Figure 3-4 Superheat ovoids



This fuel is a petcoke based ovoid made with a resin binder. This is a non-approved fuel, which is smoky (>5g/hr) and has a high sulphur content (>2%). Following introduction of The Air Quality (Domestic Solid

Fuels Standards) (England) Regulations 2020[6] this fuel is not available for residential use in England and is currently only sold in Scotland. Superheat fuel was supplied by CPL directly in sealed plastic bags, 25kg each.

As a manufactured solid fuel, the shape and size of each ovoid is very uniform, measuring around 3” in length by 2” wide and around 1” thick. This fuel used in WP2 of the test program is now no longer available as it has been discontinued by the manufacturer. Similar fuels remain in manufacture and have been used in WP3 of the project.

3.4 COFFEE LOGS

Figure 3-5 Coffee logs

Coffee logs were sourced from an online retailer but most main national DIY stores (B&Q, Wickes etc.) sold this product but the manufacturer has since gone into administration.

They were advertised as ‘bio-bean Coffee Logs - Eco-Friendly Fire Logs for Wood Burners and Multi-Fuel Stoves’, and sold in paper bags of 16 logs each.

It is difficult to find other manufacturers’ products on the market. The retail price is similar to the other manufactured wood-based heat logs.

Coffee logs used for testing showed a moisture level of around 8%, which is typically somewhere in between seasoned and kiln dried firewood. Sulphur content was significantly below other manufactured fuels at 0.04%. Net and gross calorific values were approximately a third lower than the other manufactured fuels tested.

Compared to wood logs, coffee logs are a smaller size. Some coffee logs can crumble in transport and while burning.

When burning, coffee logs produce more smoke than seasoned or kiln dried wood. They also burn relatively hot and fast; modern stoves with good air supply controls allow for the burn rate to be slowed down.

The manufacturer states coffee logs are suitable for burning in wood burning stoves and multi fuel stoves.

[6] Available here : https://www.legislation.gov.uk/uksi/2020/1095/contents/made

4. APPLIANCES

4.1 DRIVERS FOR SOLID FUEL APPLIANCE DEVELOPMENT

The procurement of stoves and open fires was an important part of the project as the appliance choice had an impact on the emissions factors. Defra required the selection of stoves to represent the installed base in the UK and to capture the significant developments in stove performance at breakpoints of years 2000, 2010, current (Ecodesign and better – clearSkies Mark 2 or above). Note that in addition to the clearSkies ecolabel, the HETAS Cleaner Choice ecolabel provides third party certification of stoves in the UK and a range of ecolabels are available in other countries.

The drivers for stove development over time which has driven improved performance have been:

Introduction of the Construction Products Directive[7]: For stoves, demonstration of conformity involves demonstration of key performance requirements through a harmonised EN Standard (EN13240:2001) including use of Notified Bodies to certify products, 'System 3' attestation and CE marking. However, the Standard did not consider PM emission requirements. The harmonised Standard was amended in 2004 and the threshold for efficiency was added of equal to or exceeding 50% net. The Directive has since evolved into the Construction Products Regulations and, post Brexit, CE marking has been replaced by UK Conformity Assessment.

Publication of the 2010: Domestic Building Services Compliance Guide[8] (DBSCG): This sets a minimum efficiency threshold for 'Solid fuel dry room heater - 65% gross' and for 'Simple open fire 37% gross'. The project teams' experience is that there were appliances in the market which significantly exceeded this minimum level of performance prior to this guidance being published.

Ecodesign regulation for solid fuel space heaters[9] which came into force 2022: This sets the minimum threshold for seasonal space heating energy efficiency to not be less than 65 % net, and sets emission limits for NOx, OGC, particulate, and CO. In the regulation seasonal efficiency is efficiency measured at rated output -10% for appliances without controls or electrical supplementary heating. So, a measured efficiency of not less than 75 % net must be achieved in standard type tests. The Ecodesign benchmark is seasonal efficiency of 86% net. Note that Ecodesign regulations use market surveillance to assess product performance which is markedly different from the type approval controls on Construction Products.

clearSkies[10] - Since early 2020 the clearSkies Mark certification scheme has been operating and shows that a significant number of products are available in the market that exceed the requirements of the Ecodesign regulation. Prior to the clearSkies mark an 'Ecodesign-ready' listing was available and numerous stoves were included in this for two or more years prior to clearSkies. Note that in addition to the clearSkies ecolabel, the HETAS **Cleaner Choice**[11] ecolabel provides third party certification of stoves in the UK.

The developments have impacted the performance of stoves and therefore impacted the installed base of appliances. As the appliance inventory has been built up over decades, it is not possible for a single appliance to give statistically robust representation of the products installed over timeframes of 10 or more years. The selection of appliances solely on the basis of age, however, will not necessarily result in appropriate representation of the performance of these segments of the installed population. This is highlighted by the publication of the 2010: DBSCG which set minimum efficiency thresholds which many

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[7] Construction Products Directive (Council Directive 89/106/EEC) (CPD) is a now repealed European Union Directive which aimed to remove technical barriers to trade in construction products between Member States in the European Union. The directive is now replaced by Regulation (EU) No 305/2011

[8] https://www.gov.uk/government/publications/amended-approved-document-l1b-and-domestic-building-services-compliance-guide

[9] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2015.193.01.0001.01.ENG

[10] www.clearskiesmark.org

[11] HETAS Cleaner Choice - New Scheme Raising Industry Standards

appliances were already meeting. Appliance choice should not be based just on age but also its relative performance to the installed inventory.

4.2 CATEGORIES

One appliance was selected from the following criteria with the aim to use multifuel stoves in all work packages where possible:

i. open fire
ii. pre 2000 closed stove
iii. 2000-2009 closed stove
iv. modern stove (Ecodesign-compliant, clearSkies level 2 or above)

4.3 SELECTED STOVES AND JUSTIFICATIONS

The specification of each stove can be found in Appendix A.2.

4.3.1 Open fire

The choice of open fire was a standard grate setting (Parkray Paragon inset open fire of 400 mm nominal width). This setting is used for the routine testing of manufactured smokeless fuels. It is a standard setting and is wholly appropriate for this test programme.

Parkray Paragon inset open fire no data on installations available

4.3.2 Pre 2000 closed stove

The pre 2000 closed stove proved difficult to source. Several options were found but their size was not appropriate for the test program. A suitable stove released circa. 1997 was sourced, however due to the age, there is little detail from the manufacturer as they no longer have records of their discontinued models. The 'turbo baffle' system which was part of the air system has been blocked for the test program according to manufacturer's recommendation.

Hunter Oakwood no data on installations available

4.3.3 2000-2009 closed stove

HETAS installation data collection starts from 2006. And we have used data collected between 2006 to 2009 Where there was a total of 114,636 notifications across these 4 years. HETAS commented that there are fewer manufacturers during this period and a lot fewer models, three models stood out as appropriate for this period, the following was considered the most appropriate:

Stovax / Dovre Model Dovre 500MRF (2.9%) installations across 4 years

4.3.4 Very efficient modern stove (Clear Skies level 2 or above)

HETAS guidance for choosing the final stove was from cross-checking the Clear Skies website with the installed inventory. Their selection from the period, 1st July 2020 to 30th June 2021 was selected from approximately 112,400 notifications. The model chosen is not the most popular installed but, is the most popular clearSkies model when including all the model derivatives. The stove differed from that used in WP1 and included a multifuel grate.

Charnwood Model: C4 (0.95%) 1st July 2020 to 30th June 2021.

5. WP2 POLLUTANT MEASUREMENTS

5.1 TEST PROTOCOL

Initial testing and discussions with the Steering Group informed the development of a Test Protocol, which defined how the measurement programme should be undertaken to develop the emissions factors for all the specified fuels and appliances. The Test Protocol was largely developed before the Round Robin began and was subsequently updated based on the challenges and findings from the Round Robin tests. The Test Protocol was presented to the Steering Group on 25th November 2021 and was approved for use. A final version[12] has been used in the WP2 test programme.

The test protocol addresses several considerations including:

- How to measure 'real-world' emission performance
- Consistent appliance operation
- Pollutant Measurements
- Methodology development for Black Carbon measurements and condensables characterisation
- Performance characterisation - assessments of uncertainty, variability, and accuracy of measurements through repeatability testing
- Uncertainty and accuracy of results
- Method for the creation of final emissions factors and co-operation with NAEI agency

The Test Protocol describes the equipment set up, methodology, appliance operation and operating parameters in detail and this is not duplicated in this report.

The following data were recorded by the project:

Figure 5-1 Components measured in WP2

Measurement	Measurement location	Comments
CO CO_2 TOC/HC NO_X	Appliance outlet	Continuous measurement, unweighted CO and O_2 used to standardise integrated samples. Weighted data used to standardise continuous measurements. NO_X data used in preference to dilution tunnel data.
NO_X CO CO_2 SO_2 HC	Dilution tunnel	Continuous measurements, unweighted CO data used to establish dilution ratio for integrated samples. Weighted CO data used to establish dilution ratio for continuous measurements. NO_X not used (close to limit of detection and/or too variable).
PM	Appliance outlet	Heated filter measurement, integrated samples for alternate phases of burn cycle.
PM	Dilution tunnel	Heated filter measurement, integrated samples for alternate phases of burn cycle.
Dioxins & Furans PAH Heavy metals	Dilution tunnel	Integrated samples collected over entire burn cycle (a combined sample system for PCDD/F and PAH analysis and a separate sample system for heavy metals).
PM PM_{10}, $PM_{2.5}$,	Dilution tunnel	Impactor measurement, integrated samples for alternate phases of burn cycle. PM data compared with PM at appliance outlet to assess condensable PM component (by difference).

[12] Emission Factors for Domestic Solid Fuels: Deliverable 1.1 – Test Protocol, Ref: ED 14880, Issue 1, 11/2/22

Measurement	Measurement location	Comments
PM_1		
Black carbon	Dilution tunnel	Integrated samples collected over short periods in alternate phases of burn cycle. Analysed for EC and OC. Note that a single sample was collected for each fuel and following the WP1 work, additional testing is planned in WP3.
Condensable PM	By calculation	Difference between impactor and heated filter measurements at dilution tunnel and appliance outlet respectively.

In addition, oxygen concentrations, flue gas temperatures, burn rate, appliance draught and ambient temperature were all monitored. PCDD/F, PAH, heavy metals and, in some instances, SOx have been determined using integrated samples collected over the entire burn cycle. PM species were measured during each type of phase (ignition, refuel and burnout). Samples for Black Carbon were collected for short periods during selected ignition, refuel and burnout phases with timings informed by preliminary tests at the University of Manchester. NOx, SO_2, CO, TOC, O_2 and CO_2 were monitored continuously over entire burn cycle. Some measurements were undertaken at the appliance outlet, but most emissions were measured using a dilution tunnel.

Three measurements were undertaken on each appliance + fuel combination. The test protocol included ignition, one or two refuels and a burnout phase. Note that the number of refuels depended on how quickly a fuel load was consumed for each appliance and fuel combination. Fewer refuels were undertaken in WP2 than were completed in WP1 where three refuels were needed to provide sufficient burn duration to replicate real world operation of 4 hours. Refuels for the mineral fuels were reduced because these fuels have longer burn periods, more than twice the length of the wood fuels used in WP1. This adjustment is needed because seasoned wood log which might take 40 minutes to burn down before a reload of fuel is required whereas a mineral fuel burn period might take 1 hour 30 minutes. The mineral fuel tests therefore only required 1 refuel in order to meet the four-hour burn duration.

The amount of fuel used in each test was also different to WP1 as the amount of fuel depended on the appliance and fuel type under test. This is because the primary air supply through the grate is the main source of combustion air for mineral fuels and MSF. This is a key difference compared to wood fuels for which the main combustion air is from secondary air (air wash). The covering of the grate is therefore very important for effective and consistent combustion for mineral solid fuels. If part of the grate is left uncovered, then combustion air will bypass the fuel bed and the fuel will only burn partially. As the grate sizes vary between stoves the mass of fuel needed to cover the grates changes therefore the mass of fuel used varies between appliance + fuel combination.

All measurements in WP2 were conducted on the test rig constructed at Kiwa, Cheltenham, with Kiwa and ECL undertaking measurements.

5.1.1 Changes to the Test Protocol

During Work Package 1, Ricardo carried out an audit of the Kiwa test facility to ensure that measurements were being carried out in line with the agreed Test Protocol. This includes a modified DIN+ methodology (from the DIN + certification scheme for “Room Heaters for solid fuels with low-pollution combustion” according to DIN EN 13240 and CEN/TS 15883:2009). The manufacturer of the DIN+ equipment had determined that these systems do not require filter clamps to allow exposure of the whole filter to the gas flow. The vertical orientation of the holder and the pressure drop across the filter required in the DIN + system holds the filter in place.

However, the auditor was concerned that due to the filters not being clamped there is a possibility of particulate material evading the surface of the first filter and escaping around the sides of filter in the filter housing. Thorough investigations into this potential issue were carried out in 2022 and are reported in detail in the WP1 Report. As a result, for WP2 an O-ring was installed in the filter housing to eliminate the risk of bypass by evasion. The WP2 measurement programme started without a filter seal but most measurements were undertaken with seals in place (see Table 5-1).

To ensure all particulate matter passing through the filter enclosure is accounted for, the o-rings were washed with isopropyl alcohol (IPA) cleaner after each test. IPA was selected due to its compatibility with the high temperature Viton rubber and quick evaporation. The washings were collected, IPA evaporated, and leftover matter weighed. This weight was then recorded in the test log sheet. This procedure was similar to that used for recovery of the heated line washings.

5.1.2 Measurement Issues

Although some of the burn cycles proved difficult to control (particularly on the older appliances), the continuous monitoring data indicate that emission trends and burn rates during consecutive burn cycles were consistent. Maintaining a high level of dilution proved difficult on some appliances including the open fireplace.

Evaluation of the data has required considerable review to resolve data issues including gaps and jumps in data. One test on anthracite fuel was aborted as the fire could not be recovered at a refuel.

The WP2 metals measurements indicate that the range of metals concentrations for some metals (in particular copper, chromium and nickel) is very high for some appliance and fuel combinations. Variation in the other metals is much smaller. Work (in WP3) has indicated that material recovered from the probe surfaces prior to the filter was the main reason for particulate phase variation (see Section 6.2.9). The Steering Group have approved a process for identifying and disregarding anomalous data.

5.2 TEST SCHEDULE

The test schedule is summarised in Table 5-1.

Table 5-1 Emission test programme

Test Week	Date of Test	Filter seal Y/N	Stove	Fuel
1	04/05/2022	N	Modern Stove	Coal Trebles
1	05/05/2022	N	Modern Stove	Coal Trebles
1	06/05/2022	N	Modern Stove	Coal Trebles
2	09/05/2022	N	Modern Stove	Superheat
2	10/05/2022	N	Modern Stove	Superheat
2	11/05/2022	N	Modern Stove	Superheat
3	17/05/2022	N	Modern Stove	Heat Approved
3	18/05/2022	N	Modern Stove	Heat Approved
3	20/05/2022	N	Modern Stove	Heat Approved
4	24/05/2022	N	Dovre Stove	Heat Approved
4	25/05/2022	N	Dovre Stove	Heat Approved
4	26/05/2022	N	Dovre Stove	Heat Approved
5	30/05/2022	N	Dovre Stove	Superheat
5	31/05/2022	N	Dovre Stove	Superheat
5	01/06/2022	N	Dovre Stove	Superheat
6	07/06/2022	N	Dovre Stove	Coal Trebles
6	08/06/2022	N	Dovre Stove	Coal Trebles
6	09/06/2022	N	Dovre Stove	Coal Trebles
7	14/06/2022	N	Old Stove	Superheat
7	15/06/2022	N	Old Stove	Superheat
7	16/06/2022	N	Old Stove	Superheat

Test Week	Date of Test	Filter seal Y/N	Stove	Fuel
8	12/07/2022	Y	Old Stove	Heat Approved
8	13/07/2022	Y	Old Stove	Heat Approved
8	14/07/2022	Y	Old Stove	Heat Approved
9	19/07/2022	Y	Old Stove	Coal Trebles
9	20/07/2022	Y	Old Stove	Coal Trebles
9	21/07/2022	Y	Old Stove	Coal Trebles
10	26/07/2022	Y	Open Fire	Superheat
10	27/07/2022	Y	Open Fire	Superheat
10	28/07/2022	Y	Open Fire	Superheat
11	02/08/2022	Y	Open Fire	Heat Approved
11	03/08/2022	Y	Open Fire	Heat Approved
11	04/08/2022	Y	Open Fire	Heat Approved
12	09/08/2022	Y	Open Fire	Coal Trebles
12	10/08/2022	Y	Open Fire	Coal Trebles
12	11/08/2022	Y	Open Fire	Coal Trebles
13	16/08/2022	Y	Modern Stove	Coffee Logs
13	17/08/2022	Y	Modern Stove	Coffee Logs
13	18/08/2022	Y	Modern Stove	Coffee Logs
14	23/08/2022	Y	Dovre Stove	Coffee Logs
14	24/08/2022	Y	Dovre Stove	Coffee Logs
14	25/08/2022	Y	Dovre Stove	Coffee Logs
15	30/08/2022	Y	Old Stove	Coffee Logs
15	31/08/2022	Y	Old Stove	Coffee Logs
15	01/09/2022	Y	Old Stove	Coffee Logs
16	06/09/2022	Y	Open Fire	Coffee Logs
16	07/09/2022	Y	Open Fire	Coffee Logs
16	08/09/2022	Y	Open Fire	Coffee Logs
17	15/09/2022	Y	Modern Stove	Anthracite
17	20/09/2022	Y	Modern Stove	Anthracite
17	21/09/2022	Y	Modern Stove	Anthracite
18	22/09/2022	Y	Dovre Stove	Anthracite
18	27/09/2022	Y	Dovre Stove	Anthracite
18	28/09/2022	Y	Dovre Stove	Anthracite
19	29/09/2022	Y	Old Stove	Anthracite
19	04/10/2022	Y	Old Stove	Anthracite
19	05/10/2022	Y	Old Stove	Anthracite

5.3 AUDIT

As part of the test programme an audit by Ricardo was undertaken at Kiwa's test facility to ensure that the methodology that had been proposed and agreed by the project steering group had been correctly implemented during WP2 testing. This audit found that the tests observed were undertaken methodically by competent staff following procedures and measurement standards so there can be confidence in the data provided. A small number of minor recommendations and suggestions were made by the auditor and a full audit report was prepared and shared with Kiwa and ECL to enable recommendations to be considered and implemented. These were:

- Gaseous probes measuring close to the wall are in a position where they are influenced by other probes (dilution section).
- PVC connections between hot components of the sample system may deform and leak (stack section).
- Differences in calibration gases - suggest checking each by passing through both systems.
- Condensation on the particle size (Dekati) filters. Filter heaters not heating the filter housing sufficiently to prevent condensation.
- Kiwa NOx converter efficiency should be checked.
- Dioxin and metals filter papers (incorrect size or filter assembly) should be checked to ensure particulate material cannot evade the media.

5.4 QUALITY ASSURANCE AND QUALITY CONTROL

5.4.1 Importance of QA/QC

The emission factors developed through this project will be used directly in the UK National Atmospheric Emissions Inventory (NAEI), which fulfils reporting requirements under the National Emissions Ceiling Directive (NECD) (transposed into UK law as the National Emissions Ceiling Regulations (NECR); the United Nations Economic Commission for Europe (UNECE)'s Convention on Long Range Transboundary Air Pollution (CLRTAP).

In addition to fulfilling the national and international reporting requirements, the NAEI provides emissions data for a wide range of other uses including providing policy makers and the public with an understanding of the key polluting sources, how these sources have varied over time and how they are likely to contribute to pollution in the future. NAEI data are publicly available via https://naei.beis.gov.uk and their uses include:

- Annual National and Official Statistics reporting.
- Input into models used for academic research and policy making (including Pollution Climate Mapping and UK Integrated Assessment Model) and analysis by expert groups on air quality.
- Input into ambient air quality mapping for compliance assessments against the requirements of the Fourth Daughter Directive (2004/107/EC) and the Ambient Air Quality Directive (2008/50/EC) and assessment against Air Quality Strategy Objectives.
- Development and assessing progress of national air quality plans.
- Local and regional reporting including production of inventories for England, Scotland, Wales and Northern Ireland, Local Air Quality Management and Clean Air Zones.
- Responding to Freedom of Information Act and Environmental Information Regulation requests, Parliamentary Questions and general queries from the public.

It is therefore critical that the measurements and derived emission factors are of high quality, and subject to checks that give the users confidence in the reported data – particularly around uncertainty of the emission factors data and applicability to UK domestic burning. It is a key responsibility of the Steering Group to guide the project team in this respect and communication with the Steering Group has been frequent and valuable.

5.4.2 QA/QC of measurements and outputs

The initial phase of the project included test protocol development, which was subsequently used to determine repeatability and reproducibility of the protocol, through round-robin testing within the laboratories at Kiwa, Leeds and Manchester. Analysis of the round robin data has provided an understanding of the uncertainties associated with the test protocol.

The main body of the work of testing of appliances and fuels has been undertaken in the Kiwa laboratory. Testing of solid fuel appliances undertaken under Kiwa's laboratory accreditation supported by the systems required by the testing laboratory standard (ISO 17025) and the relevant appliance standards (BS EN 16510-1, BS EN 13240 and BS EN 13229). For this work the appliance operation protocol has sometimes been different to those defined in appliance testing standards, as described and explained in the Test Protocol, but the support systems of sensor calibration, data collection and checking for accredited work have been applied throughout WP2. Where changes to methods were required, these have been documented in this report and/or in the Test Protocol and have been validated during the development and round-robin activities.

Regular checks have been carried out to ensure equipment is calibrated and working within specification. For measurements of components at the dilution tunnel (gaseous pollutants, PCDD/PCDF, PAH & Heavy Metals) sampling has been undertaken in accordance with the ECL Procedures based on EN Standards but with some deviations to combine sampling (for example mercury and other metals and, PAH and PCDD/F). Where possible, testing has been undertaken in accordance with ECL's organizational MCERTS accreditation, by MCERTS qualified personnel and with MCERTS approved monitoring equipment to ensure that the highest quality of data is obtained.

Analytical methodologies have been applied as described in the Test Protocol. Compositional analyses of fuel samples have been undertaken at accredited test laboratories. The accuracy and uncertainty of results from accredited laboratories is reported with the results of the measurements.

An emission monitoring audit has been carried out during WP2 to assess compliance with the agreed test protocol and measurement methods. This has provided assurance that the test protocol and measurement methods have been followed and has identified improvements which have since been implemented.

Automatic logging of data has been used where possible, with additional manual quality checks to check completeness and accuracy. Other data and metadata have been recorded manually in a dated and signed laboratory book, or electronically with associated files. On completion of WP2 all documents, datasets and other relevant files will be provided to Defra, with a backup held by Ricardo.

5.5 UNCERTAINTY ASSESSMENT

The uncertainty in the final emission factors comprises a range of contributing elements including:

- Representativeness of the appliances
- Variation in fuels
- Variation in operation
- Measurement – include measurement method, sampling protocol, analysis LoD, calibration/reference materials
- Data handling – data acquisition, storage and handling – the processes to work up the measured data into the final emission factors.

5.5.1 Appliance representativeness

The test programme in WP2 has been on four appliances which have been selected as representing different types of solid fuel room heater technology used in UK. The choice of type of appliance was based on the broad types of appliance categories (open/stove) and aligned the stove age classification used in the NAEI to a technology type (basic control/secondary air/secondary and tertiary air) as set out to the EFDSF steering group earlier in the project. The EFDSF steering group helped identify the most popular installed stoves in recent years (used to choose the modern stove) and also provided information on the older appliances. The choice of appliance has been endorsed by the EFDSF steering group – recognising that it is a small subset of the diverse range of appliances in use in UK.

5.5.2 Fuel type and quality

The procurement of the fuel has been undertaken to ensure as much as possible the consistency of the fuel to improve uncertainty in the testing. All the five fuel types detailed in section 3 have been procured as a single batch from either the manufacturer or as with the coffee logs and anthracite a third-party supplier. This was done to ensure that the fuel is consistent as possible and from the same source / batch with each of the fuels stored together in stable conditions throughout the test programme to ensure fuel properties such as moisture remain constant between tests.

There are two main characteristics which are different between the fuels which impact the uncertainty of the results: material consistency and shape. Three of the fuel types are manufactured fuels which are formed into a product of consistent material and shape. This helps to reduce the uncertainty of the testing as the consistent material ensures tests are burning the same material and the consistent shape ensures the fuels distribution within the stove is consistent. The remaining fuels, House Coal trebles and Anthracite small nuts are formed naturally in rock strata which are mined and screened to provide a fuel of similar sized pieces. The uniformity of these naturally formed fuels is therefore less consistent than the MSF products with the size and shape of the fuels also making the distribution in the fuel bed less consistent.

The increased number of fuel pieces used when tests with the two MSFs, coal and anthracite will help to reduce overall uncertainty between tests. This is because the variation in the average distribution of fuel within the stove is reduced when there are more pieces of fuel and the burn rate and air distribution is easier to manage maintain between tests. This removes some of the randomness of fuel distribution caused by large pieces of fuel which can impact testing. Coffee logs are large pieces of fuel and the way they break down inside the stove during combustion changes the distribution of the fuel inside the stove and therefore burn rates and air distribution increasing the uncertainty in the results. Every care has been taken to ensure that the stoves are refuelled identically for each load to minimise this uncertainty.

5.5.3 Operation

The appliance test cycle for the measurement programme is based on the typical UK hours of use and, comprises an ignition phase, normal operation with refuels and a burnout phase (based on the Defra burning survey and an indoor air quality survey). The number of refuels depends on the duration of the burn and is aimed at replicating typical UK hours of use. For mineral fuels the number of refuels was 1 with the coffee logs requiring 3 refuels. Aggregate emission factors have been constructed for this test cycle based on combining each of these phases for each test. Note that it is possible, for some pollutants, to calculate other aggregations for example as a sensitivity check or to reflect different durations of operation.

5.5.4 Measurement

The appliance test protocol includes test methods which draw on EN Standards and/or EN Technical Specifications for emission and appliance testing but with compromises to reflect the challenges of sampling emissions from a small, batch-fired combustion appliance and a bespoke test protocol. Where no EN Standard exists we have used literature and research to guide the test methodology. The main measurements have been undertaken by IEC/ISO 17025 accredited test houses – recognising that many of the measurements are outside the scope of accreditation (because of changes from the accredited test methods to accommodate the test protocol and constraints of the test facility). For example, measurement during ignition (appliance testing) and combined PAH and PCDD/F sampling (emission testing). However, the test protocol reflects the objectives of the project and incorporated suggestions from the steering group to align operation closer with real-world operating conditions (around draught).

Measurement uncertainties provided by the test houses for the reported concentrations do not reflect uncertainties in the choice of appliance, test protocol or fuel but selected uncertainties are shown in Table 5-2.

Some measurements have more uncertainty than others due to a range of factors including analytical uncertainty. The analysis of the individual PCDD/F congeners indicated that although some congeners in the tests were reported as below the field blank[13] there were relatively few (11 out of 168) tests where the tetra and penta-chlorinated PCDD congeners and penta-chlorinated PCDF congeners with the highest toxic equivalent factors were below the LoD. In the PAH samples, the four compounds used

[13] The measurement procedure requires a blank sample to be prepared and recovered at the measurement site for each group of tests (one field blank for each set of three tests) – the field bank is prepared and recovered in the same way as a measurement sample except no flue gases are sampled.

for international reporting were found above the LoD in all tests. Chloranthene, was below the LoD for 15 of the 57 tests in these cases the field blank value is used however contribution to totals (assuming present at field blank concentration) was <<1%. For the metals testing there were 57 occurrences out of 784 measurements when the metals were below the field blank value. In these cases the field blank concentration was used instead, most of these occurred for coal trebles for a variety of the metal pollutants.

5.5.5 Data handling

For some pollutants integrated samples were collected over the entire test cycle (PCDD/F, PAH, metals), some were measured continuously over the entire test cycle and data have also been gathered for each phase of operation (CO, NOx, SO_2, TOC). For some pollutants, integrated samples were collected in selected phases of operation – ignition, 2nd refuel and burn out (PM, PM size). These latter samples were taken from one refuel phase (of up to three) so are likely to have higher uncertainty than measurement which sampled all phases of operation.

In addition to the measurement uncertainties all pollutants have required data manipulation to get from concentrations to emission factors:

1. Application of a dilution ratio based on CO concentrations measured at appliance outlet and dilution tunnel
2. Standardisation of undiluted concentration to a reference oxygen content
3. Application of a conversion factor to calculate an emission factor
4. Aggregation of short-term emission factors to cover the entire burn cycle.

These operations contribute additional uncertainty to the measurement uncertainty.

Three sets of measurements were undertaken for each fuel and appliance combination, and this has allowed calculation of standard deviation and other indicators of repeatability. The EMEP/EEA Guidebook confidence intervals for emission factors are generally (much) larger but are typically based on expert judgment to assign an indicative uncertainty range. This reflects the challenges in understanding the uncertainty from combining emission factors reported by a range of studies (or calculated from reported data) with differing objectives, different appliances and often different measurement approaches.

Table 5-2 Selected measurement uncertainties

Measurement	Lab	Maximum Allowed Uncertainty of Method (MCERTS), %	Range of recorded uncertainty
Concentrations			
PCDD/F	ECL	30%	15 – 25%
PAH	ECL	30%	15 – 25%
SO_X	ECL	20%	10 – 20%
TOC	ECL	15%*	15 – 25%
CO	ECL	6%*	5 – 15%
			Method uncertainty
CO	Kiwa		6%
NO_X	Kiwa		±1.2 ppm
CO_2	Kiwa		2%
O_2	Kiwa		2%

PM	Kiwa		0.29g/h
Other			
Appliance/Fuel weight	Kiwa		±20g
Fuel load	Kiwa		±5g
Flue gas Draught	Kiwa		±2Pa
Flue gas temp	Kiwa		±5°C

- MCERTS maximum allowed uncertainties are for application on industrial activities (specifically ‘Part A’ activities regulated under Schedule 1 of the Environmental Permitting Regulations (England & Wales) 2016 and equivalent in Scotland and Northern Ireland).
- MCERTS TOC and CO uncertainties are defined in terms of Emission Limit Values (ELVs) for TOC and CO but ELVs for stoves are not applicable for measurement on diluted exhaust gases.
- PM uncertainty is for DIN+ PM test method (at appliance outlet).

6. EMISSION FACTORS

6.1 METHODOLOGY

The measurement programme provided:

- continuously monitored emission concentration data throughout the different phases of the burning cycle for some gaseous measurements (CO, CO_2, O_2, NOx, SO_2,TOC),
- an integrated concentration measurement for (PCDD/F, PAH and metals) over the whole burn cycle,
- integrated PM-related concentrations measurements for alternate phases of the burning cycle (ignition, an operation phase and burnout phases).

Measurements were generally undertaken at the dilution tunnel with selected measurements also undertaken at the appliance outlet.

Emission measurements were generally provided as concentrations (a volume or mass in a known volume of sampled gas). Continuously monitored data has a weighting to adjust for different burn rate at each 1-minute average data point (not applied to integrated samples). Black carbon and particle size data were reported as weights or similar metric and were developed into concentrations based on sample duration and reported sampling rate.

The calculation of emission factors for each appliance and fuel combination from the emission concentration data reported by the test houses required several calculation stages:

- Initial data check to confirm concentration provided at STP (0°C, 101.3kPa) and dry gas for period sampled, identification of odd data for review.
- Conversion to a mass concentration at STP for a dry gas (where required).
- Correction to undiluted concentration applying ratio of CO determined at appliance outlet and dilution tunnel (where required).
- Standardising to a reference oxygen concentration (13% O_2).
- Converting to a g/GJ net heat input emission factor by applying a stoichiometric dry flue gas volume (adjusted to 13% O_2) for each fuel (see Table 3-1).
- Aggregating emission factors for each phase for full burn cycle (weighted for fuel burned in each phase).
- Averaging for each appliance/fuel combination (3 tests to single value).

The procedure used the same methodology and calculation template as used in WP1 but modified for different measurements, fuel characteristics and number of refuels.

Some components were determined from an integrated sample collected across the entire burn cycle, others from integrated samples from selected phases of the burn cycle and, some using continuous monitoring data. Where possible, average concentrations have been calculated for each phase (ignition, refuel and burnout phases) and then developed into emission factors. An aggregate emission factor for the entire burn cycle was then constructed using the weight of fuel burned in each phase to develop a weighted average.

For continuously-monitored pollutants, data were recorded as one-minute averages and an additional weighting was undertaken to reflect variation of fuel burn rate during each phase – that is, the weighted average in each phase reflects the combination of emission concentration and burn rate at the minute average data.

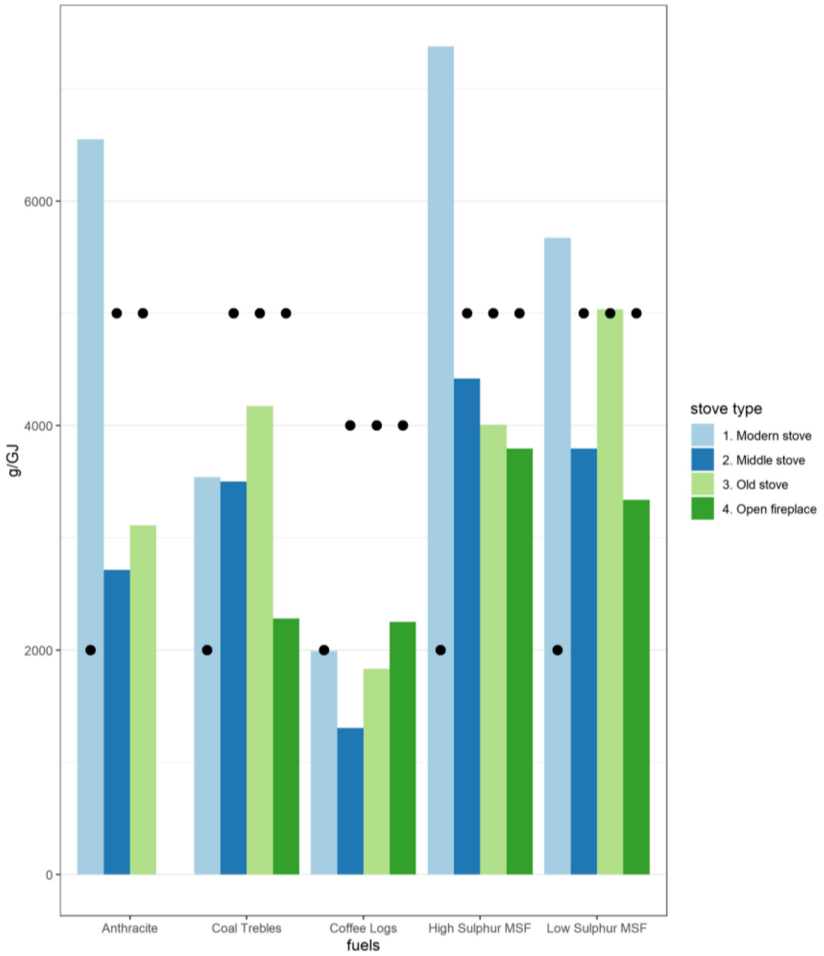
6.2 SUMMARY OF EMISSION FACTORS

The figures below provide a summary of selected emission factor data to illustrate emissions from fuels and appliances. The coloured bars represent emission factors for each fuel and appliance with the **black dots** representing the associated existing NAEI emission factor from the most recent inventory submission for the fuel and technology. Note that emissions from use of coffee logs are not currently included in the NAEI and emission factors for coffee logs have been compared with emission factors for wood/solid biomass. The emission factors for coal, anthracite and manufactured solid fuels are proposed for inclusion in the NAEI for the 2025 inventory submission.

It is notable that for the modern Ecodesign appliance using mineral fuels that there are higher emission factors for CO, PM and TOC/OGC (which have emission limits in the Ecodesign Regulation) and PCDD/F and PAH compared to the older appliances. Smaller differences in emission factors will be mitigated by higher energy efficiency for the modern appliance but elevated emission factors are often higher than could be offset by improved energy efficiency.

6.2.1 Carbon monoxide (CO)

Figure 6-1 Carbon monoxide emission factors



Carbon monoxide emission factors were generally highest for the modern appliance for each fuel (except coffee logs where the open fire provided the highest emission factor). The lowest CO emission factors were found using coffee logs with the highest emission factors generally for the manufactured mineral fuels. In general emission factors were lower than the comparable emission factor used in the NAEI and EMEP/EEA Guidebook 2019 but notably the emission factors for the modern appliance for the solid mineral fuels were higher (and higher than emission factors determined for older stoves and the open fireplace).

6.2.2 Particulate matter

As described in Section 5.1.1, WP2 test work commenced with the same equipment as used in WP1. The modification to include an o-ring for the heated filter measurements was introduced after completion of seven weeks of the WP2 test programme. Following extensive investigations (detailed in the Work Package 1 report) and discussion with the Steering Group, this study uses PM data from the dilution tunnel particle size measurement data (Dekati) for initial measurements taken during WP2 when there was no o-ring in place to prevent leakage around the heated filter (as done for WP1 data). For measurements where there was an o-ring in place, data from the dilution tunnel heated filter is used.

Although the impact of the o-ring was limited compared to WP1, the adopted approach for initial data from WP2 is consistent with treatment of PM data in WP1.

Figure 6-2 Total Particulate matter emission factors

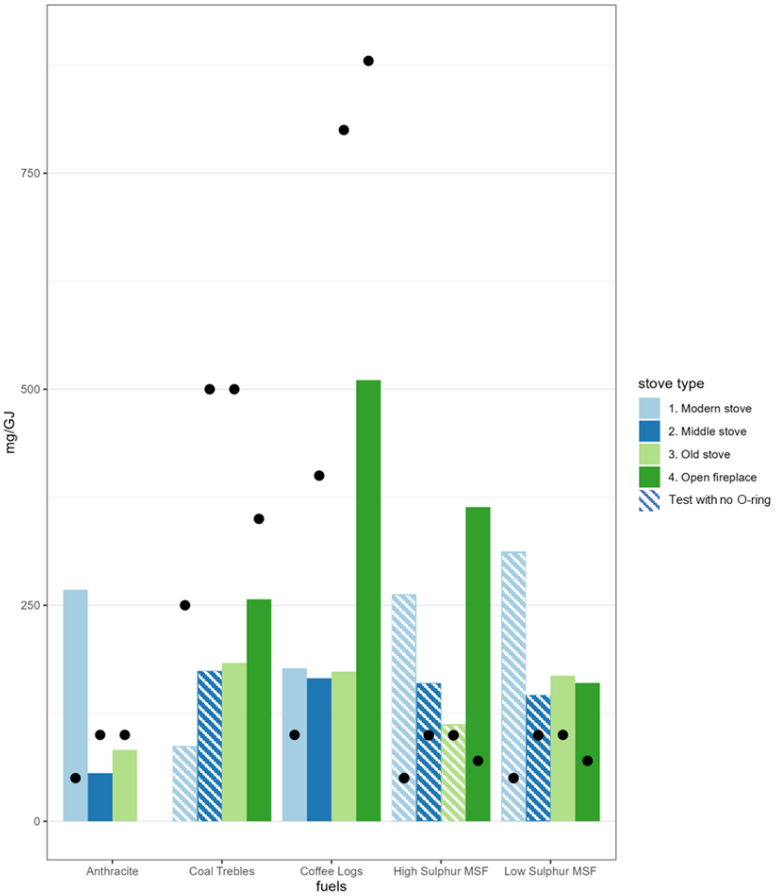
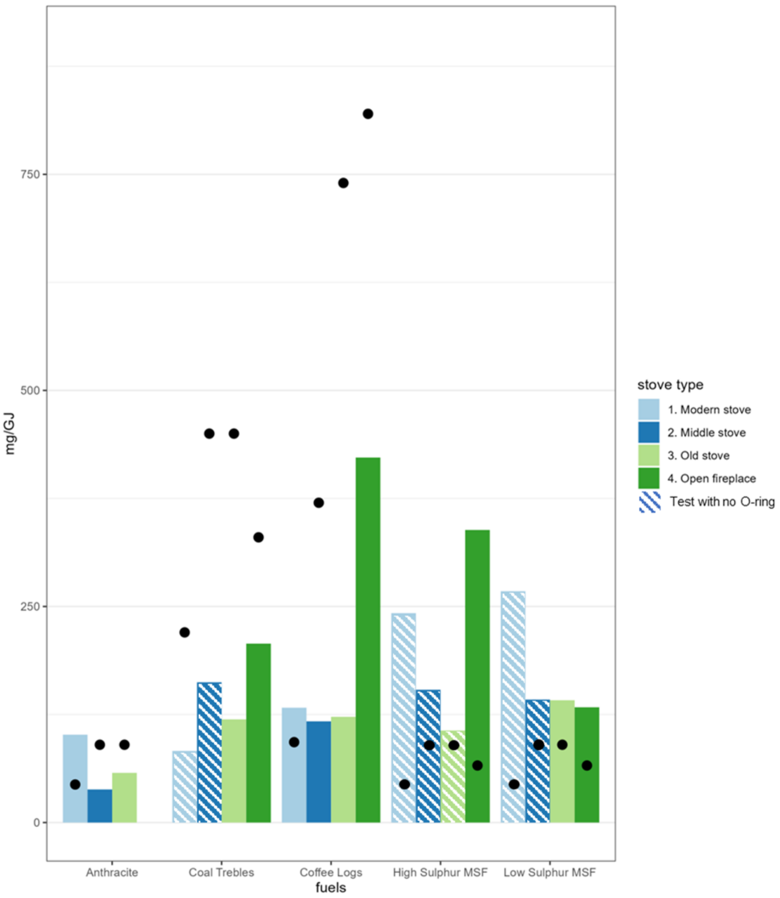
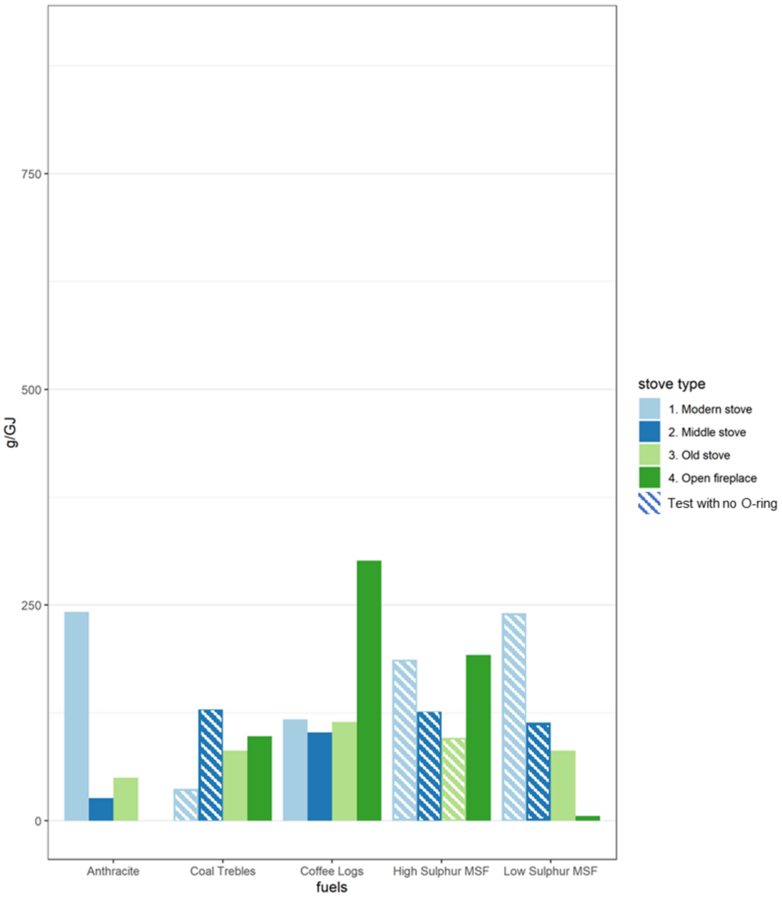


Figure 6-3 $PM_{2.5}$ emission factors



For TPM and $PM_{2.5}$, the emission factors determined for anthracite, coal and coffee logs are generally lower than the emission factors used by the NAEI but for the manufactured fuels, the emission factors are higher than current NAEI emission factors. For condensable PM which is not currently reported in the NAEI (Figure 6-4), the emission factors are highest for the modern stove burning anthracite and the MSF fuels and, for the open fire when burning coffee logs. The relatively high contribution from condensable PM for anthracite and MSFs (on the modern stove) is a little surprising as these fuels have a low volatile matter content or are sold as smokeless products. The condensable PM emission factors appear lower on the other closed appliances.

Figure 6-4 Condensable PM emission factors



6.2.3 Total organic compounds (HC/OGC/TOC)

The NAEI reports methane and non-methane volatile organic compounds (NMVOC) separately. In the test programme, the measurements are of total organic compounds (TOC but sometimes known as OGC or total hydrocarbons). Figure 6-5 compares the measured TOC emission factors with the sum of the NAEI methane and NMVOC emission factors. Figure 6-6 summarises NMVOC emission factors derived from the measured TOC emission factors with subtraction of the NAEI methane emission factors. The NMVOC emission factors derived in WP2 are generally lower than the NAEI emission factors for coal, anthracite, coffee logs and low sulphur manufactured fuel. However, the modern stove had higher emission factors when burning anthracite and the manufactured solid mineral fuels than applied in the NAEI.

Figure 6-5 Total Organic Compounds emission factors

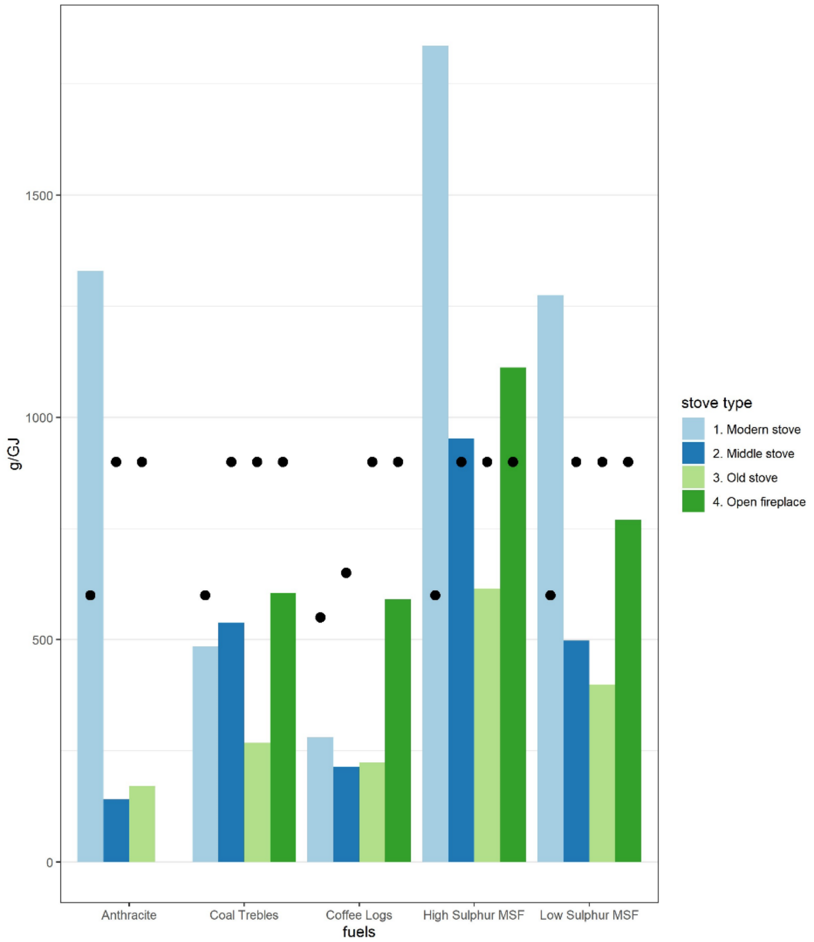
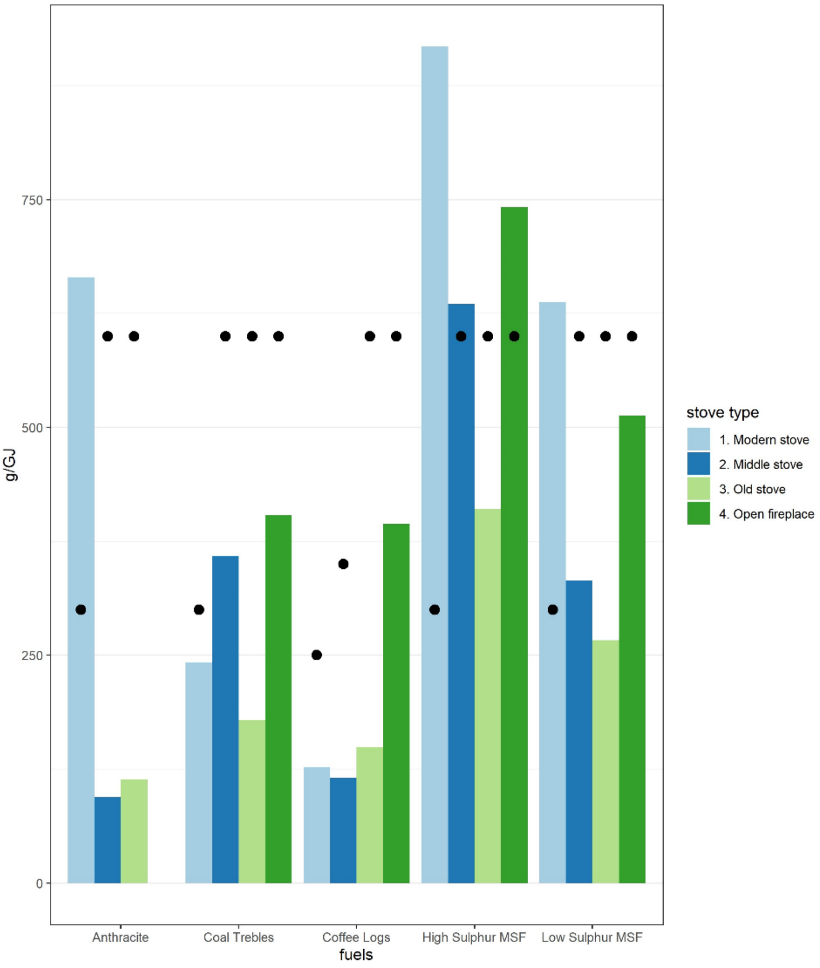


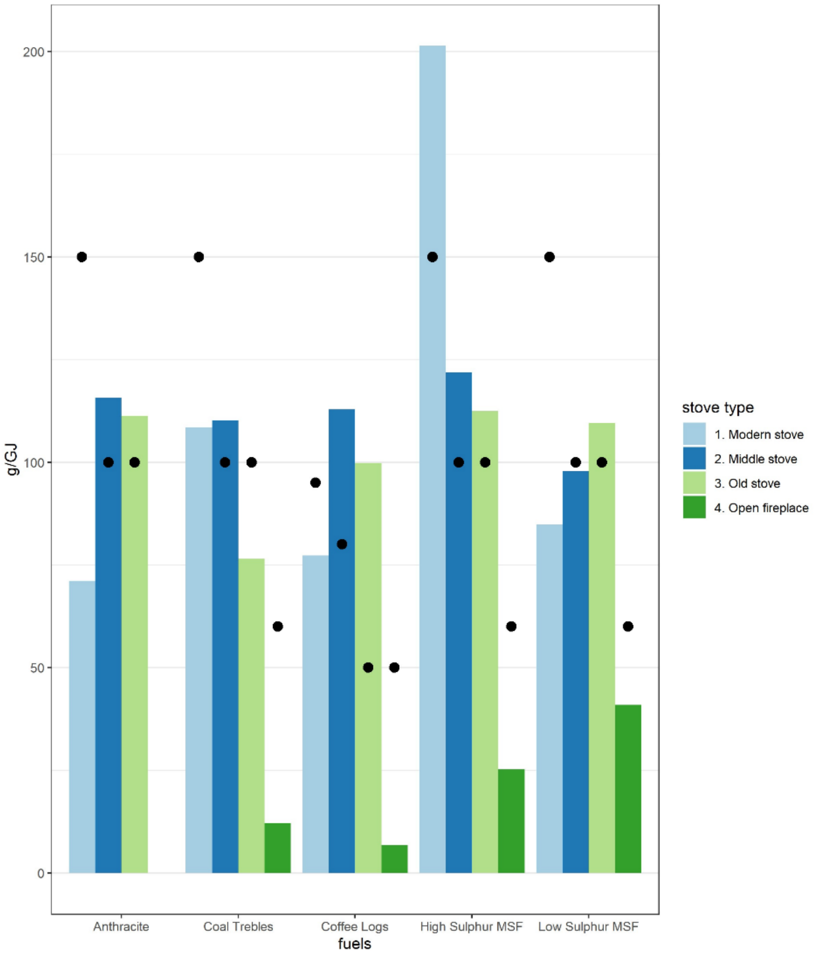
Figure 6-6 NMVOC emission factors



6.2.4 Nitrogen oxides (NO_X)

Emission factors for NO_X are broadly similar for the stoves but lower for the open fireplace (see Figure 6-7). The highest emission factor was for the modern appliance for the high sulphur 'Superheat' fuel. The emission factors used in the NAEI for modern stoves and open fires are typically higher than measured (apart from Superheat fuel on the modern stove).

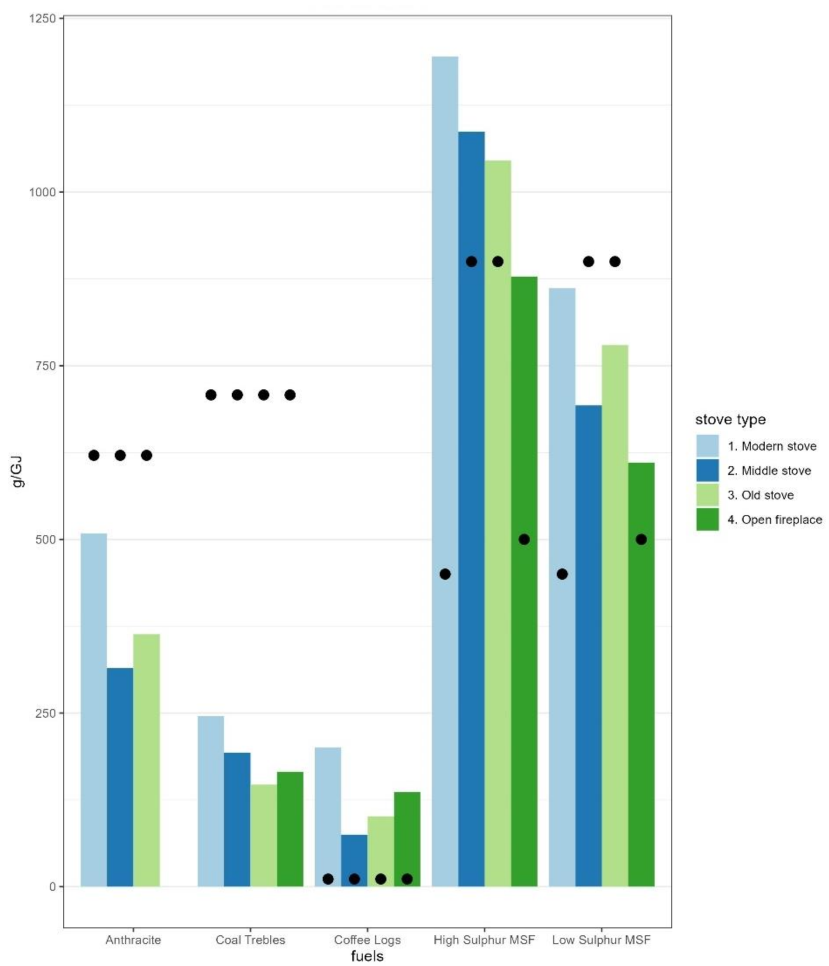
Figure 6-7 NO_X emission factors



6.2.5 Sulphur oxides (SOx)

Note that emission factors represent sulphur dioxide (SO_2) as they are derived from an SO_2 continuous measurement system. Emission factors for sulphur oxides vary between fuels more so than between appliance type. The highest emissions are seen for the manufactured solid fuels. Compared to the current NAEI emission factors the manufactured fuels and the Coffee Logs are generally higher (but are compared with emission factors for wood). Anthracite and Coal Trebles both have lower sulphur dioxide emission factors in this test programme than estimated in the current NAEI. Note that the NAEI emission factors are derived from sulphur analysis provided by fuel suppliers but, the number of mines and suppliers of coal has decreased over recent years, and this has had an impact on the uncertainty of sulphur data provided to the NAEI.

Figure 6-8 Sulphur dioxide emission factors



6.2.6 Dioxin and furans (PCDD/F)

Figure 6-9 PCDD/F Emission factors

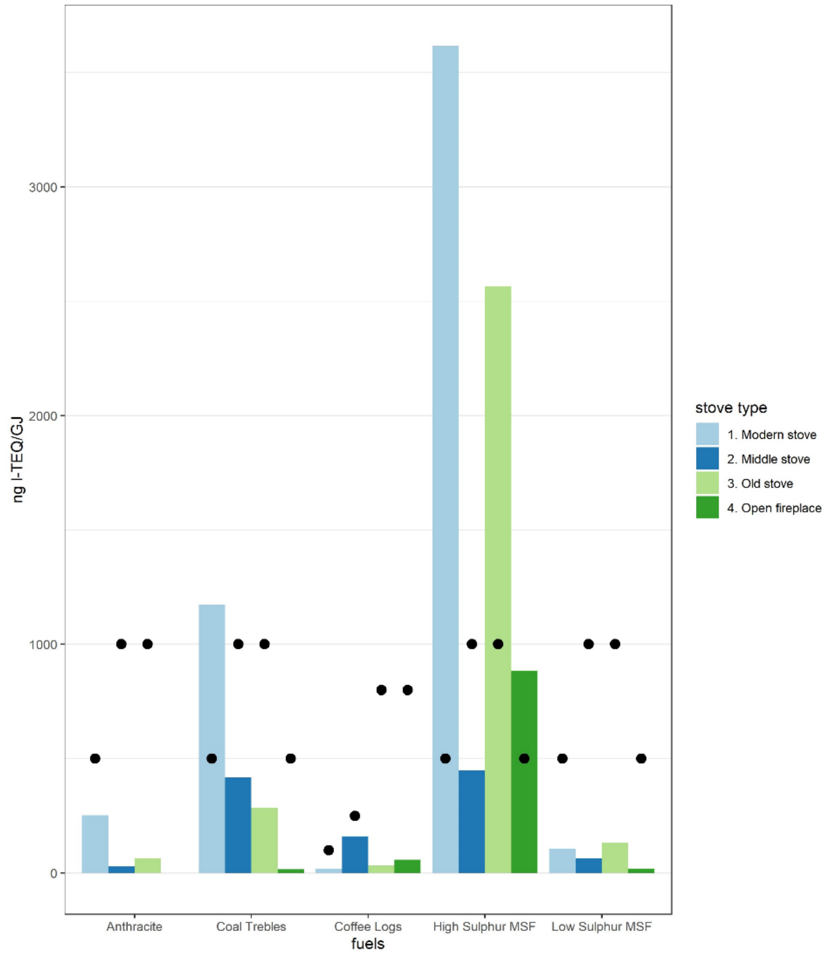


Figure 6-9 shows the PCDD/F emission factors determined in WP2. Emission factors were generally lower than the NAEI default emission factors. The highest emissions were observed with the 'Superheat' fuel when burned on the modern and old stoves; PCDD/F emission factors for 'Heat Approved', the other manufactured solid (mineral) fuel, were lower than for the Superheat fuel.

6.2.7 Polynuclear Aromatic Hydrocarbons (PAH)

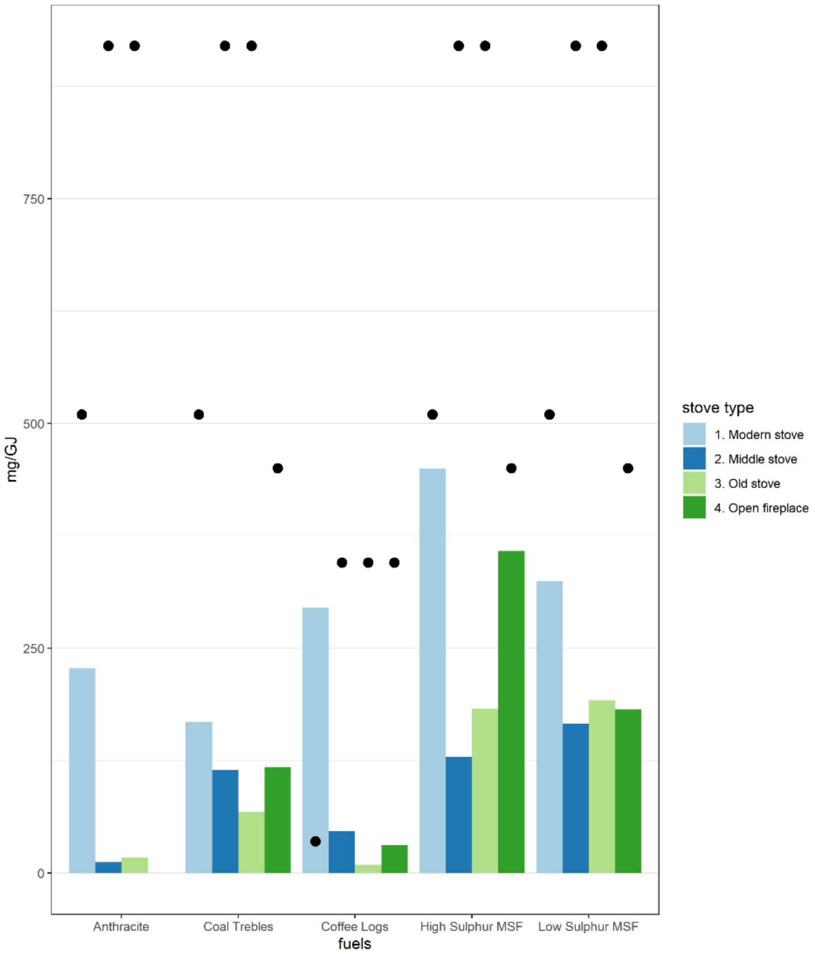
A suite of 16 PAH were determined:

- Anthanthrene
- Benzo(a)anthracene
- **Benzo(a)pyrene**
- **Benzo(b)fluoranthene**
- Benzo(b)naptho(2,1-d)thiophene
- Benzo(c)phenanthrene
- Benzo(ghi)Perylene
- **Benzo(k)fluoranthene**
- Cholanthrene

- Chrysene
- Cyclopenta(cd)pyrene
- Dibenzo (ai)pyrene
- Dibenzo(ah)anthracene
- Fluoranthene
- **Indeno(123-cd)pyrene**
- Naphthalene

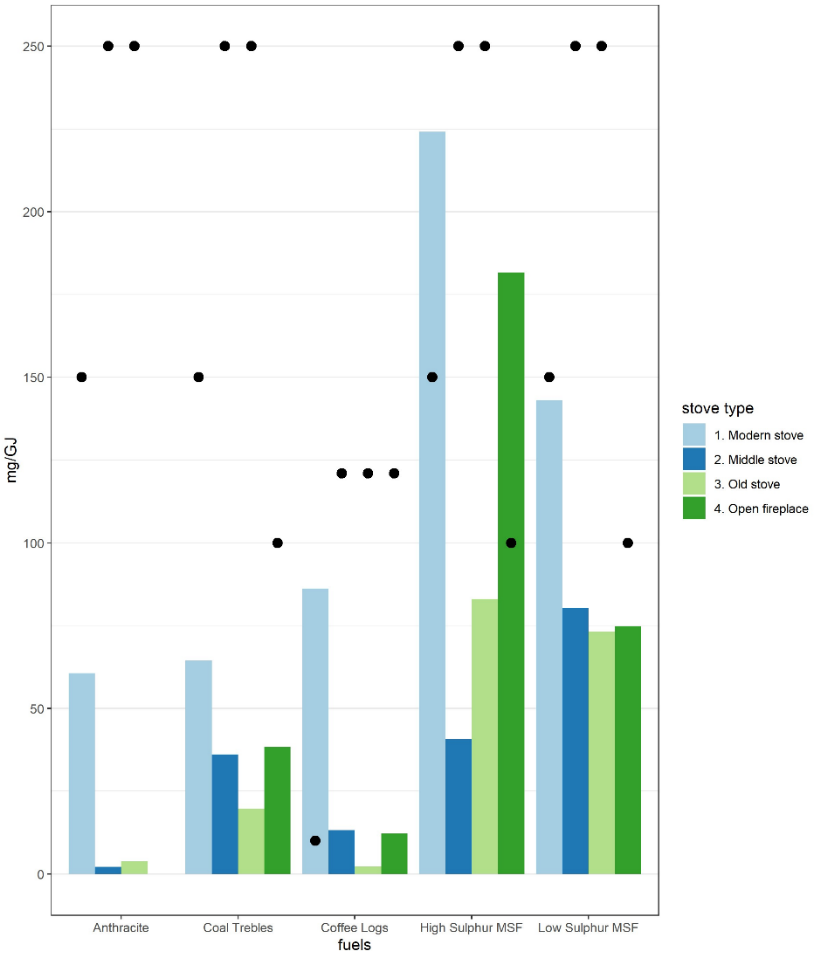
The PAH highlighted in **bold** are used for international emission inventory reporting.

Figure 6-10 PAH emission factors



Sixteen PAH compounds were determined, however only four are used for international reporting for emission inventories. Figure 6-10 compares the sum of the four PAH used in international reporting from the WP2 measurement programme with emission factors used in the NAEI. Benzo(a)pyrene emission factors are shown in Figure 6-11. The PAH emission factors determined for solid mineral fuels were all lower than the NAEI default factors. However, emission factors for the modern appliance when burning coffee logs are higher than Guidebook Tier 2 default emission factor for wood. The emission factors determined on the modern stove were highest for all fuels. Findings for B(a)P emission factors are broadly similar as for PAH.

Figure 6-11 Benzo(a)pyrene emission factors



6.2.8 Black Carbon

These represent measurement of Elemental Carbon and data are presented for information as following feedback after WP1, additional emission sampling is being undertaken in WP3 to provide more data.

Unlike other measurements, black carbon (BC) emission factors are for a single test cycle – one sample collected in each type of operating phase (ignition, operation and burnout) from one of three tests for each fuel and appliance combination. The additional measurements in WP3 are intended to provide at least three sets of samples for each fuel and technology combination.

The BC results are expressed as percentages of the $PM_{2.5}$ emission factor and a small number of samples for individual operating phases indicated BC quantities higher than the $PM_{2.5}$ for the same phase. For the mid-age stove the overall BC emission factor was higher than the overall $PM_{2.5}$ emission factor (see Table 6-1). The BC samples are collected over a shorter sampling period than the $PM_{2.5}$ samples so it is possible that sampling coincided with a period of relatively high emission.

Table 6-1 Black carbon emission factors

	Anthracite	Coal	Coffee logs	Superheat	Heat Approved
Appliance	BC, % of PM2.5				
Modern stove	19.8	0.2	16.9	0.9	18.3
Mid stove	>$PM_{2.5}$	2.5	25.5	2.2	2.3
Old stove	28.4	18.3	29.1	49.4	1.5
Open fireplace	Not tested	17.2	2.1	2.7	23.7

6.2.9 Heavy Metals

A suite of fourteen metals were sampled:

- Antimony (Sb)
- **Arsenic (As)**
- **Cadmium (Cd)**
- **Chromium (Cr)**
- Cobalt (Co)
- **Copper (Cu)**
- **Lead (Pb)**
- Manganese (Mn)
- **Mercury (Hg)**
- **Nickel (Ni)**
- **Selenium (Se)**
- Thallium (Th)
- Vanadium (V)
- **Zinc (Zn)**

The metals highlighted in **bold** are reported in the NAEI and emission results are illustrated in the following figures. Metals were sampled to collect both solid and vapour phases. Three sets of samples (and a field blank) were collected for each appliance and fuel combination in WP2.

Samples were recovered in several fractions:

- Probe rinse (particulate fraction)
- Filter (particulate fraction)
- Absorber group 1, Impinger 1 &2 (vapour phase fraction)
- Absorber group 1, Impinger 3 (vapour phase fraction)
- Absorber Group 2, Impinger 1 (vapour phase Hg fraction)
- Absorber Group 2, Impinger 2 (vapour phase Hg fraction)

The particulate fractions (filter and probe rinse) were digested prior to analysis. Absorbent solutions and washings were analysed without digestion.

Following analysis, it was noted that most metals were generally determined at or near the limit of detection however, several tests were affected by large particulate and/or gaseous contributions to selected metals for one or more of the three tests undertaken for each fuel and appliance combination. In some instances, the calculated emission factors were higher than indicated by fuel analysis and higher than NAEI emission factors (see Table 6-2).

Table 6-2 Summary of heavy metal emission factors for selected metals

Fuel and source	Cadmium	Lead	Copper	Chromium	Nickel	Mercury
	Average emission factor, mg/GJ Stoves (Open Fireplace)					
Heat Approved						
EFDSF emissions	1.2-2.6 (1.9)	31.0-37.7 (33.0)	12.2-26.3 (12.4)	31.0-**8850** (43.9)	65.8-123 (82.3)	1.8-3.6 (1.6)
EFDSF fuel analysis	1.3	201	460	376	1950	3.5
NAEI	1 (0.5)	100 (100)	15-20 (20)	10 (10)	10 (10)	5 (3)
Superheat						
EFDSF emissions	1.5-2.3 (1.3)	31.9-46.6 (57.7)	12.8-22.0 (167)	26.9-**2750** (261)	66.0-115 (336)	1.5-2.2 (2.5)
EFDSF fuel analysis	2.0	108	233	444	2980	1.0
NAEI	1 (0.5)	100 (100)	15-20 (20)	10 (10)	10 (10)	5 (3)
Coal trebles						
EFDSF emissions	1.3-2.1 (1.0)	8.0-28.4 (3.4)	7.8-**8330** (43.2)	38.7-**1350** (16.6)	53.4-**8970** (167)	1.9-3.5 (0.9)
EFDSF fuel analysis	0.7	28	195	89	132	0.3
NAEI	1 (0.5)	100 (100)	15-20 (20)	10 (10)	10 (10)	5 (3)
Anthracite						
EFDSF emissions	1.9-2.6	47.3-88.1	10.0-22.7	64.1-470	64.2-74.0	4.3-4.8
EFDSF fuel analysis	1.2	218	660	367	1000	1.8
NAEI	1	100	15-20	10	10	5
Coffee logs						
EFDSF emissions	1.5-2.9 (1.1)	19.5-152 (6.0)	11.7-36.6 (30.9)	34.3-774 (612)	70.2-181 (65.6)	1.1-2.4 (0.9)
EFDSF fuel analysis	3.5	366	687	163	136	1.0
NAEI (wood)	13 (13)	27 (27)	6 (6)	23 (23)	2 (2)	0.56 (0.56)

Additional parallel tests were undertaken to explore why high concentrations occurred – these also found high concentrations for some metals but these were not found in both sampling systems. The additional measurements were undertaken using a pair of co-located metals sampling systems operated simultaneously on the dilution tunnel with samples sent to two accredited analyst laboratories. Three pairs of measurements were undertaken on the modern appliance burning coal.

The analysis provided consistent data within the uncertainty of the analysis between the two sampling systems for vapour phase metals and for most particulate phase metals. However, for copper, nickel and manganese, the samples derived from one of the sampling systems contained much higher particulate phase concentrations than the other sampling system and higher than for other metals from the same sampling system. No material was found in the field blanks and there was no significant elevation of metal on the filters in samples with a high metal content in the probe rinse.

Review of the WP2 data indicate that, in most cases of variable particulate metals for a particular fuel and appliance group, there is at least one test with high contribution from the probe rinse fraction. Consequently, high particulate phase metals are believed to be random contamination from larger particulate material perhaps dislodged from the internal surfaces of the test facility and measures were taken to increase cleaning frequency.

For vapour phase metals, the presence of chromium could be due to migration/contamination of absorbent solution (potassium dichromate was used as an absorbant in the sampling system) however the reason for variation of other vapour phase metals was not determined. Sample recovery and preparation measures were modified to minimise the risk of such incidents.

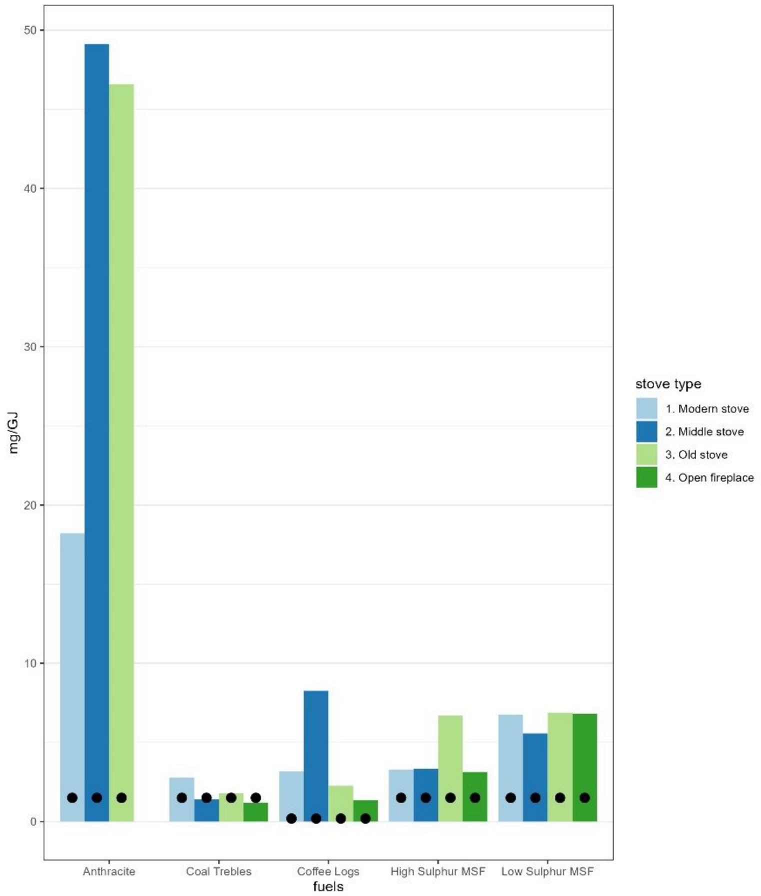
Following discussion with the project steering group, criteria were applied to data to exclude potentially anomalous results.

- Where the probe rinse is identified as a very large source of one or more particulate phase metals in a measurement, and this is not seen in the other measurements for the appliance and fuel combination, we used analysis data for affected metals from only the unaffected measurements for the fuel and appliance combination.
- Where vapour phase chromium is variable across the three measurements for the appliance and fuel combination, we did not report the contribution from vapour phase Chromium for the appliance and fuel combination. For other vapour phase metals, we used analysis data for affected metals from only the unaffected measurements for the appliance and fuel combination.

Although emission factors are reported for WP2, they are not proposed for inclusion by the NAEI at this stage. The results of further testing in WP3 will be considered with the WP2 metals data before recommending metals emission factors for use in the NAEI.

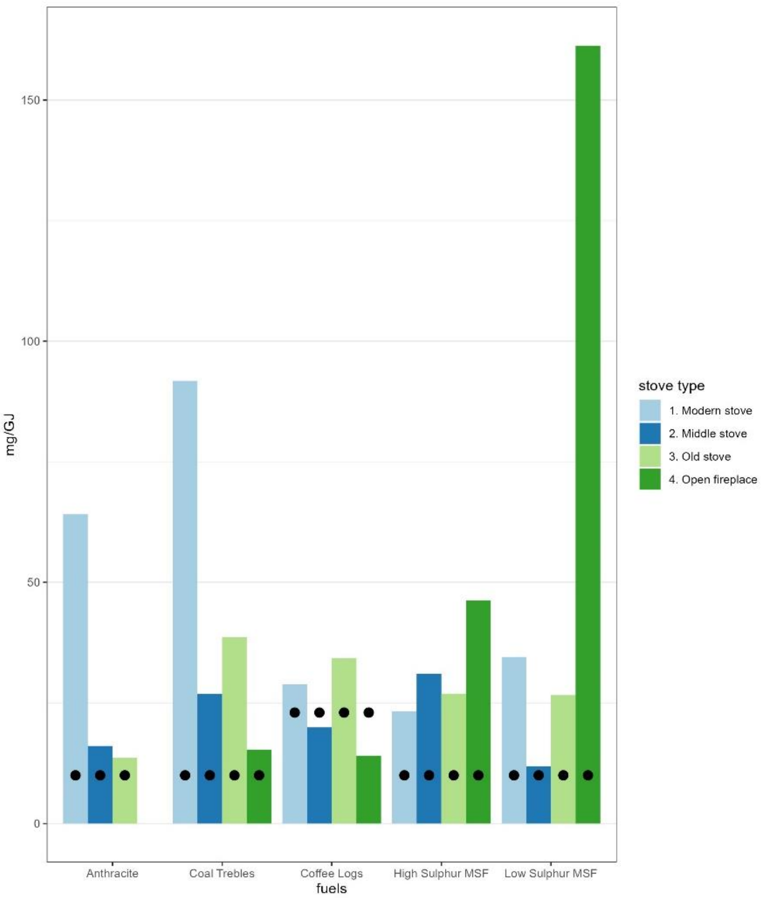
Although emission monitoring provides a well-established and standardised approach to determination of heavy metals, the measurements indicate that concentrations of most metals concentrations are at, or close to, the Limit of detection. Adoption of other approaches such as fuel and ash sampling and analysis may potentially provide data with less uncertainty.

Figure 6-12 Arsenic emission factors



Arsenic - The Arsenic emission factors calculated are generally consistent with the NAEI for each fuel type. Also the emission factor does not vary with the appliance types very much. The exception to this is the emission factors from Anthracite, these are much higher than the current NAEI factors. Additionally, the Coffee Log emission factors are more similar to the manufactured solid fuels than to wood. The data for the Middle Stove Coal Trebles had the vapour phase removed for 2 of the 3 tests due to high vapour phases recorded which were much higher than the particle phase.

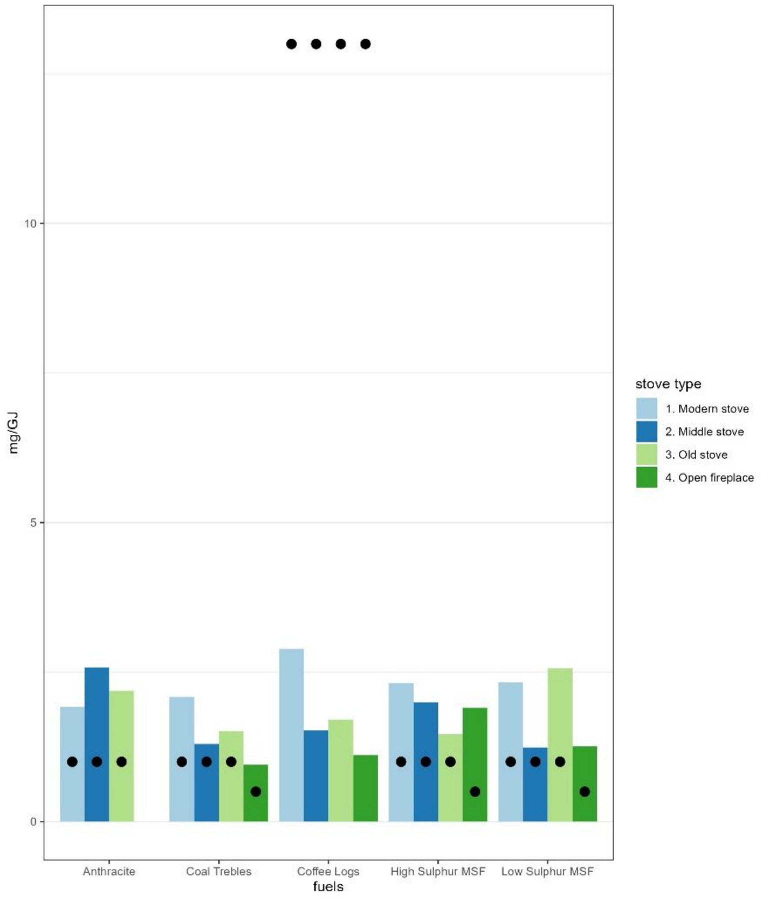
Figure 6-13 Chromium emission factors



Chromium

Chromium emission factors are variable between fuels and stoves. High vapour phase emissions were found for some tests and may be due to migration of potassium dichromate solution in the sampling train (used to collect mercury vapour). The vapour phase for chromium should be a very small fraction of the sample with most metal expected to be present in the particle phase. Where the vapour phase was the issue, the vapour phase data has been removed for all three tests and the remaining particle phase data has been used to develop an emission factor.

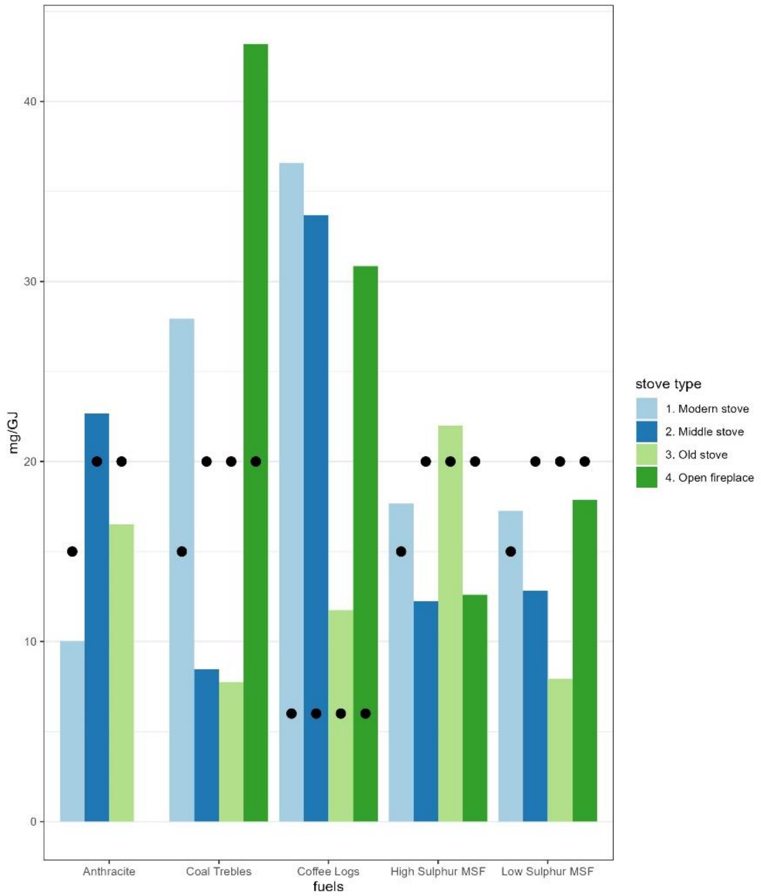
Figure 6-14 Cadmium emission factors



Cadmium

Emission factors calculated are generally in line with the NAEI factors for each fuel type and do not vary much between fuels. Also the emission factor does not vary much between appliance types although the emission factors for the open fire are lower in most cases. Emission factors for Coffee Logs are lower than the NAEI emission factors (for wood).

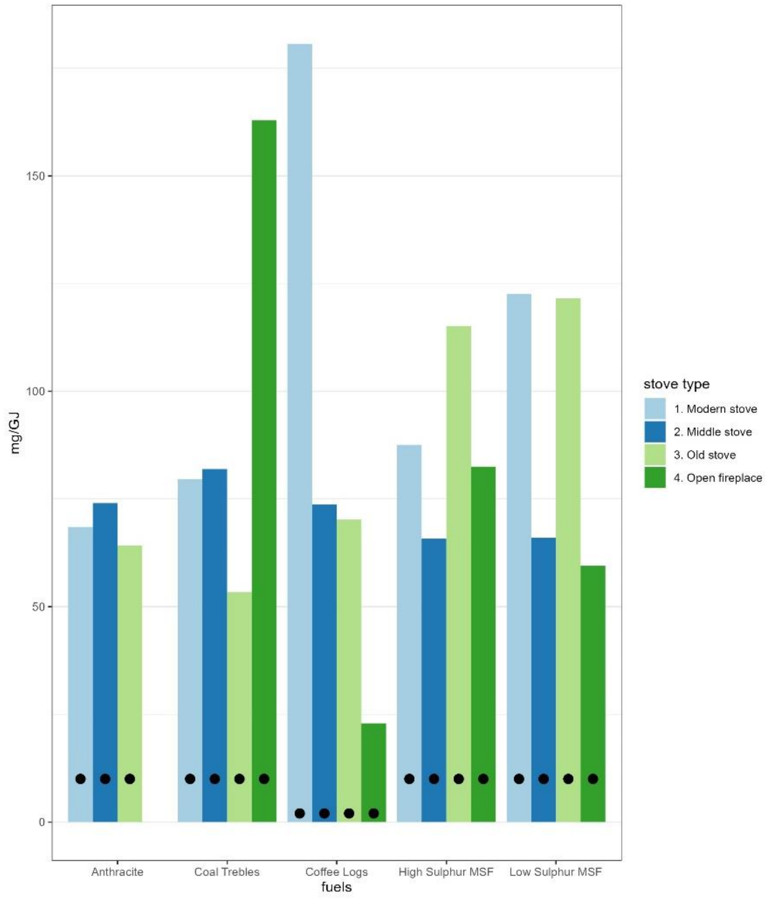
Figure 6-15 Copper emission factors



Copper

Copper emissions are quite variable between fuel and stove type. The emission factors for Anthracite and the manufactured solid fuels are quite similar to the NAEI factors. Whereas the Coal Trebles and Coffee Logs emission factors are a bit higher in most cases than expected. For some of the tests one repeat has been excluded as they were a clear outlier.

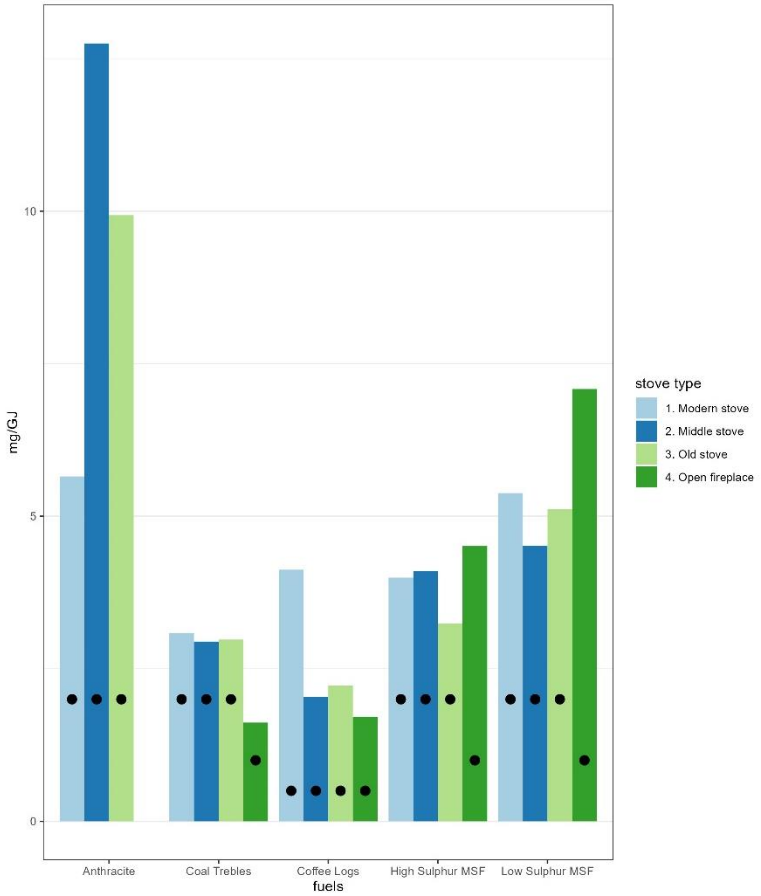
Figure 6-16 Nickel emission factors



Nickel

The nickel emission factors are all observed to be higher than the current NAEI emission factors. The highest emission factor was found for Coffee Logs in the modern stove and the lowest emission factor for coffee logs on an Open Fireplace which may suggest variation between appliances but may reflect differences in the coffee logs. For some of the tests one repeat has been excluded as they were a clear outlier.

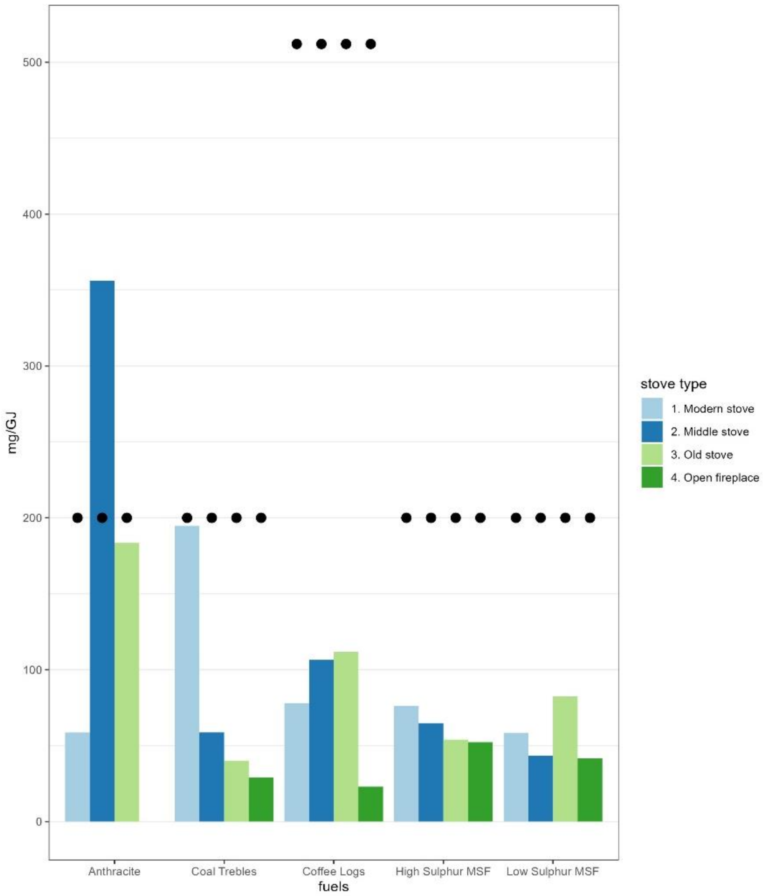
Figure 6-17 Selenium emission factors



Selenium

All emission factors are higher than the current NAEI emission factors. Coal Trebles has quite similar emission factors for the closed stoves but a reduced emission factor for the open fireplace (as in the emission factors used in the NAEI). The emission factors for Anthracite are the largest across the stove types and are larger than the NAEI factors.

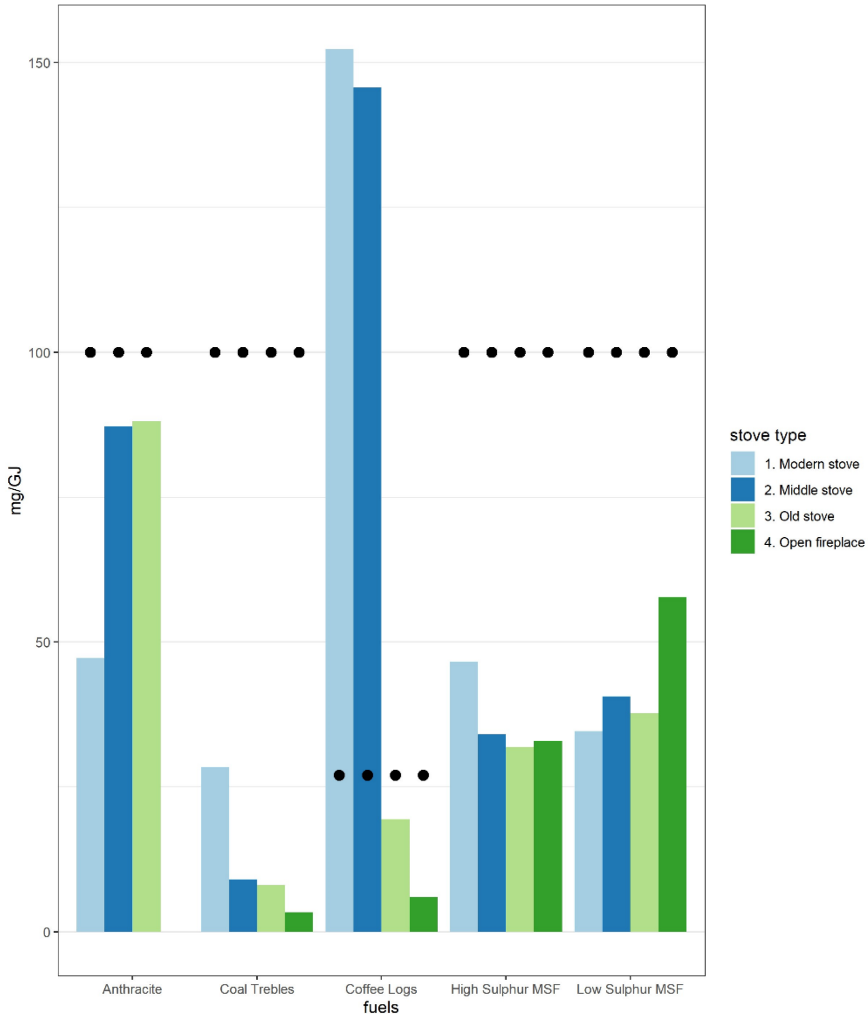
Figure 6-18 Zinc emission factors



Zinc

Zinc emission factors are generally much lower than the current NAEI factors, in particular for the Coffee Logs and manufactured solid fuel factors.

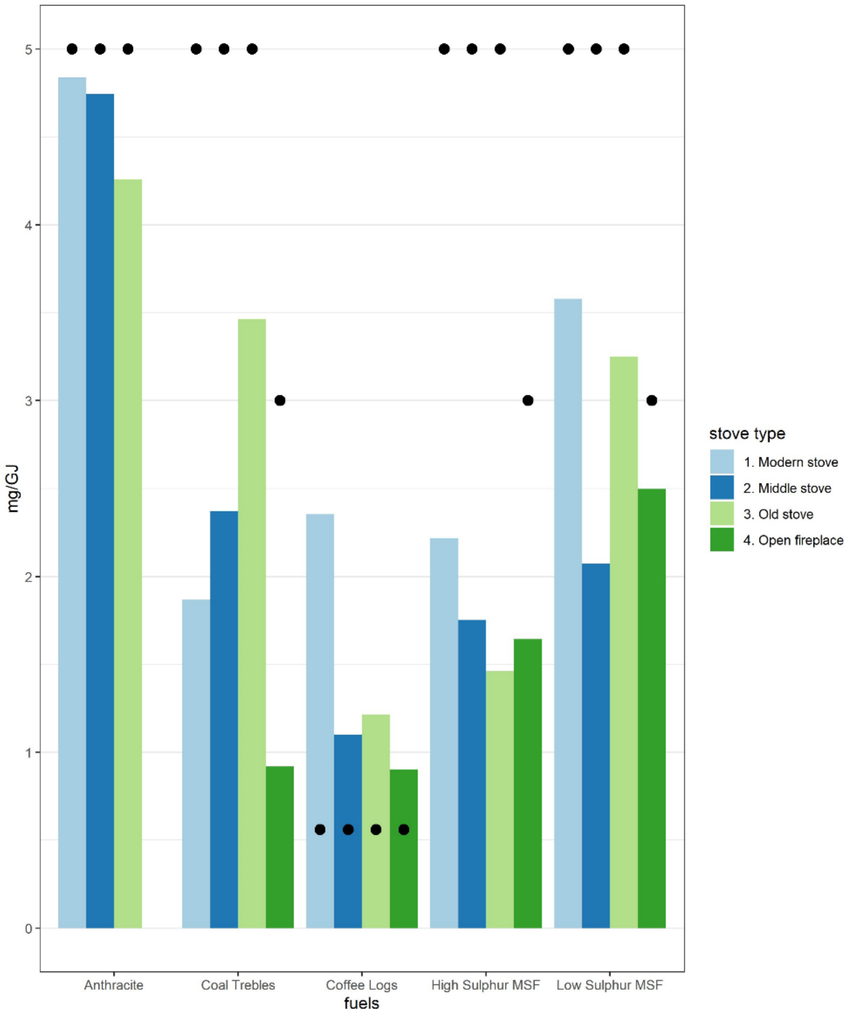
Figure 6-19 Lead emission factors



Lead

Lead emission factors are lower than the current NAEI emission factors for Coal Trebles and the manufactured solid fuels. Conversely, for Coffee Logs lead emission factors were higher than the NAEI emission factor (for wood) with variation between the stove types. The highest lead emission factors are seen for Coffee Logs burnt on the Modern Stove and Middle Stove.

Figure 6-20 Mercury emission factors



Mercury

Coal Trebles and the manufactured solid fuels show much smaller emission factors than the current NAEI values. The Anthracite emission factors are similar to those used in the NAEI. The Coffee Logs show higher emission factors for mercury than the current wood NAEI emission factors. There is some variation between the appliances.

6.3 COMPARISON WITH CURRENT NAEI EMISSION ESTIMATES

It is intended that the results from this study will be presented to the NAEI Air Quality Inventory Steering Group, which is a separate body of UK experts with responsibility for overseeing and approving major changes to the UK NAEI. In addition to the information presented earlier in this report and appendices, the AQISG will review the likely changes to the NAEI emissions as a result of implementing the new emission factors produced by this study. A series of comparative charts are shown below and show the impact of proposed emission factors on emissions from solid mineral fuel use, the residential sector (NFR 1A4bi) and National Totals.

6.3.1 Carbon monoxide

Figure 6-21 Historic impact of new EFs on CO emissions in domestic combustion (solid mineral fuels) sector

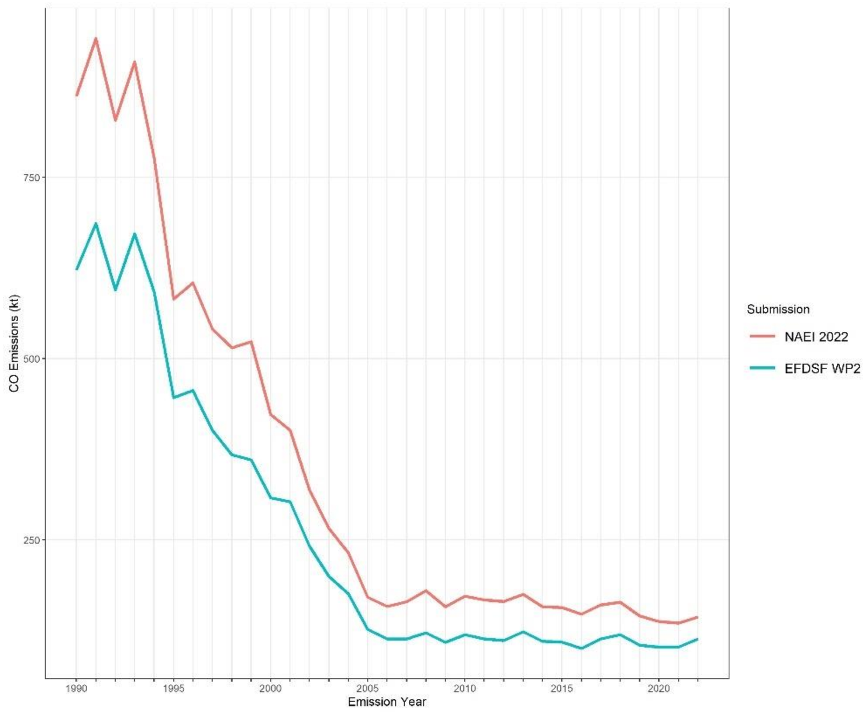


Figure 6-22 Historic impact of new EFs on CO emissions in domestic combustion sector

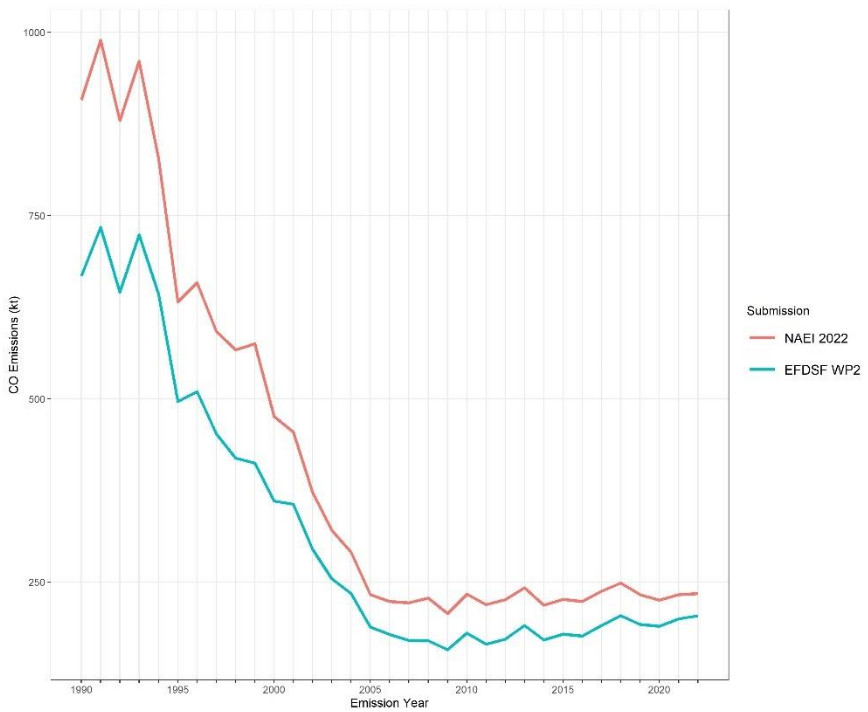
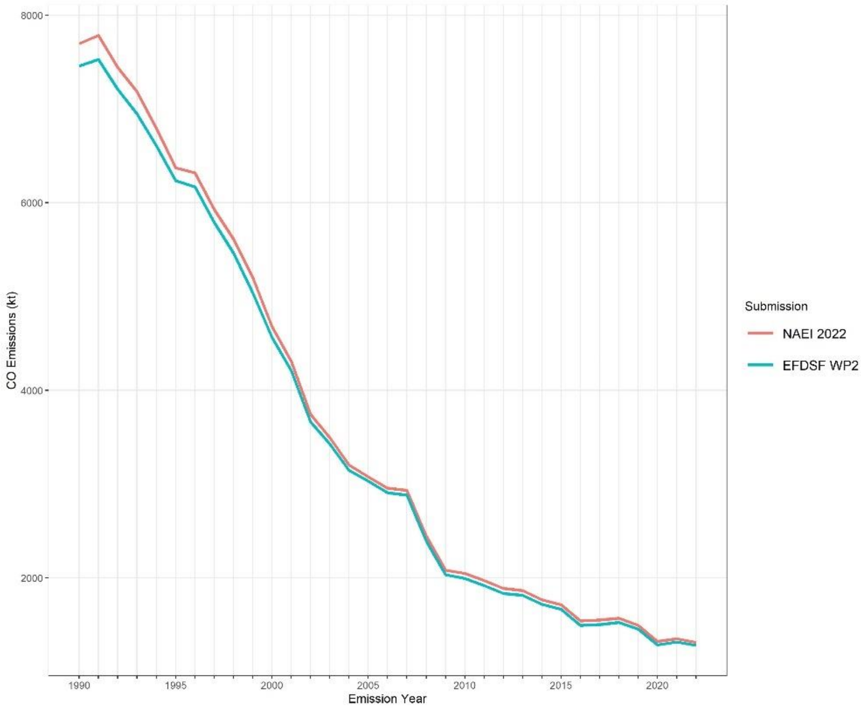


Figure 6-23 Historic impact of new EFs on CO emissions in all sectors



Although residential combustion (NFR 1A4bi) is a key source in the NAEI and revision of solid mineral fuel emission factors has a major impact on emissions attributed to solid mineral fuel and residential combustion, the impact on the national totals is small.

6.3.2 Particulate matter

Figure 6-24 Historic impact of new EFs on $PM_{2.5}$ emissions in domestic combustion (solid mineral fuels) sector

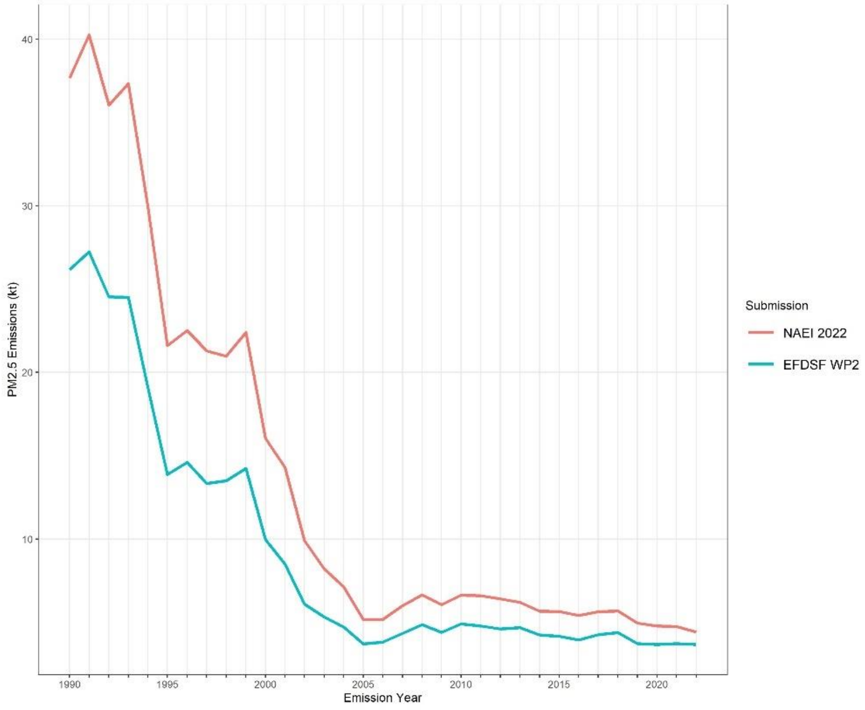


Figure 6-25 Historic impact of new EFs on $PM_{2.5}$ emissions in domestic combustion sector

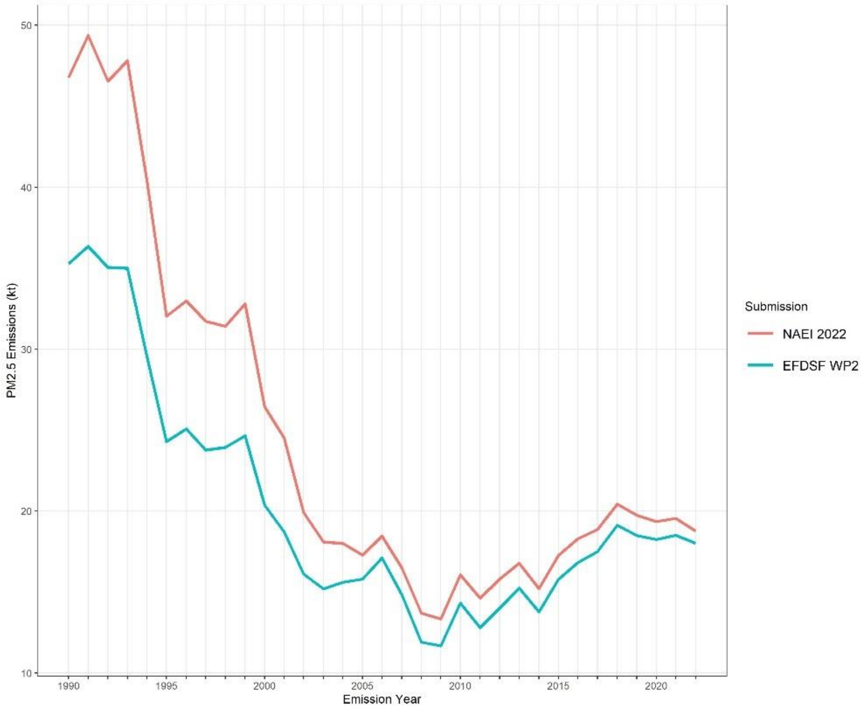
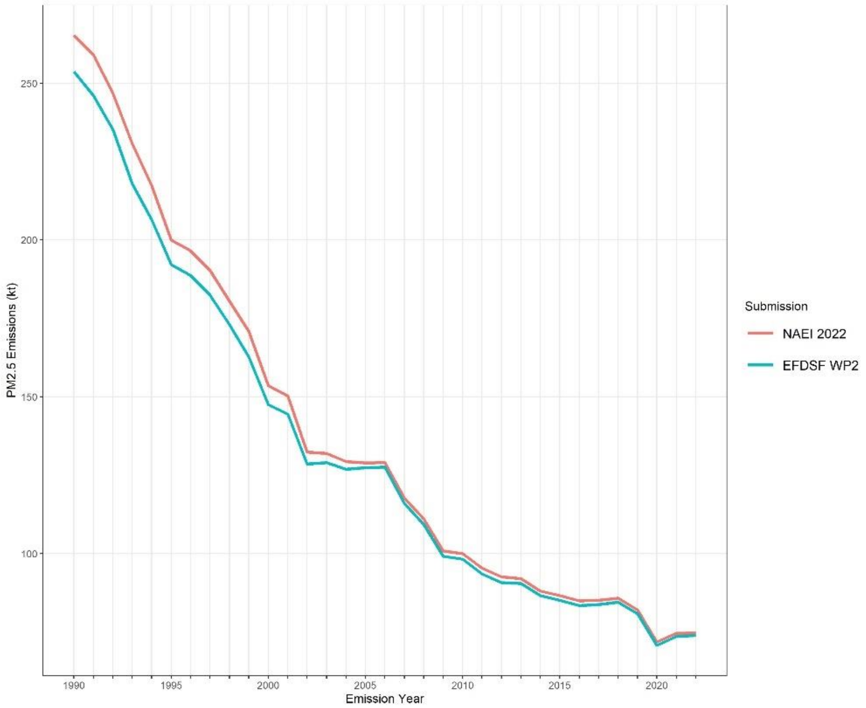


Figure 6-26 Historic impact of new EFs on $PM_{2.5}$ emissions in all sectors



Although revision of solid mineral fuel $PM_{2.5}$ emission factors has a major impact on emissions attributed to solid mineral fuel and residential combustion, the impact on the national totals is significant but relatively small in recent years (<2 ktonnes per year since 2005).

6.3.3 Non-Methane Volatile Organic Compounds

Figure 6-27 Historic impact of new EFs on NMVOC emissions in domestic combustion (solid mineral fuels) sector

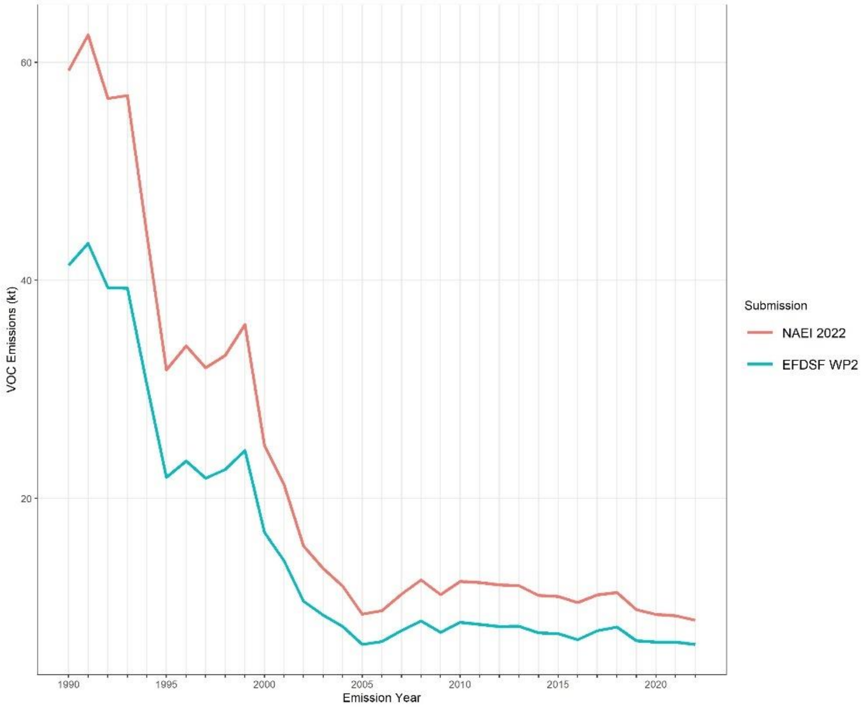


Figure 6-28 Historic impact of new EFs on NMVOC emissions in domestic combustion sector

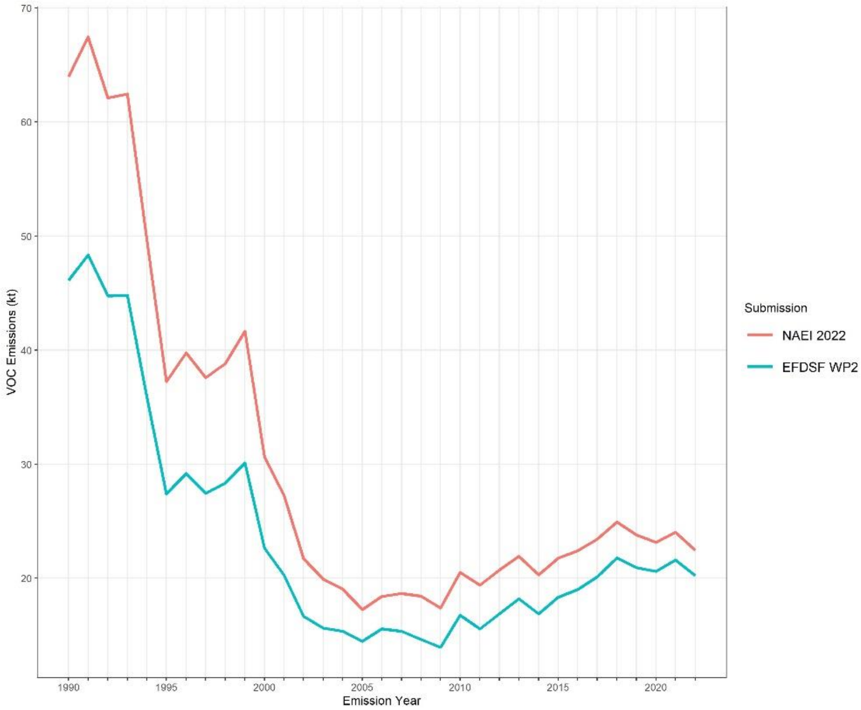
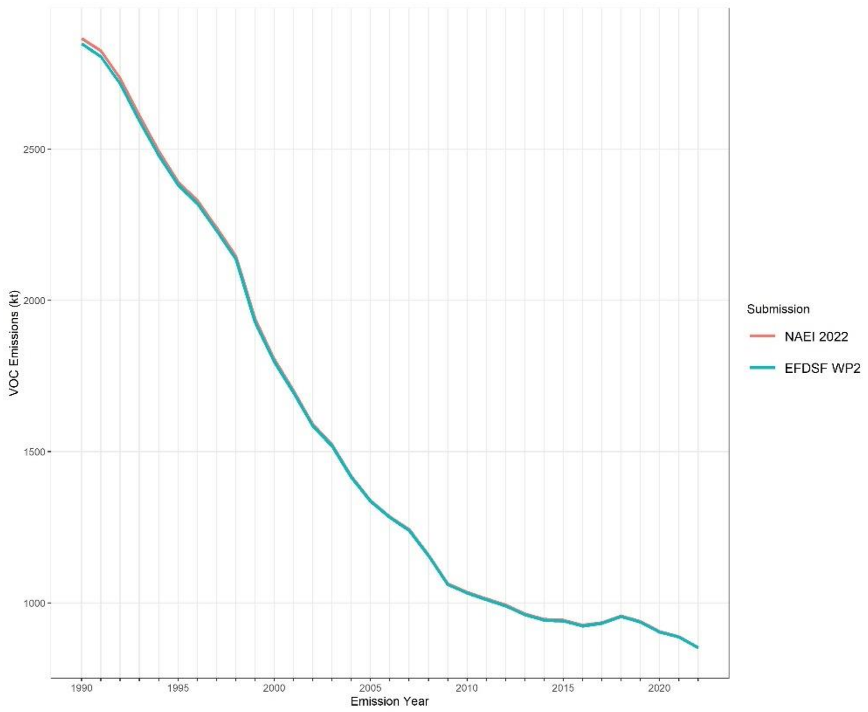


Figure 6-29 Historic impact of new EFs on NMVOC emissions in all sectors



Although revision of solid mineral fuel emission factors for VOC has a major impact on emissions attributed to solid mineral fuel and residential combustion, the impact on the national totals is small because emissions are dominated by other sources including industrial sources and use of products containing solvents.

6.3.4 Oxides of nitrogen

Figure 6-30 Historic impact of new EFs on NO_x emissions in domestic combustion (solid mineral fuels) sector

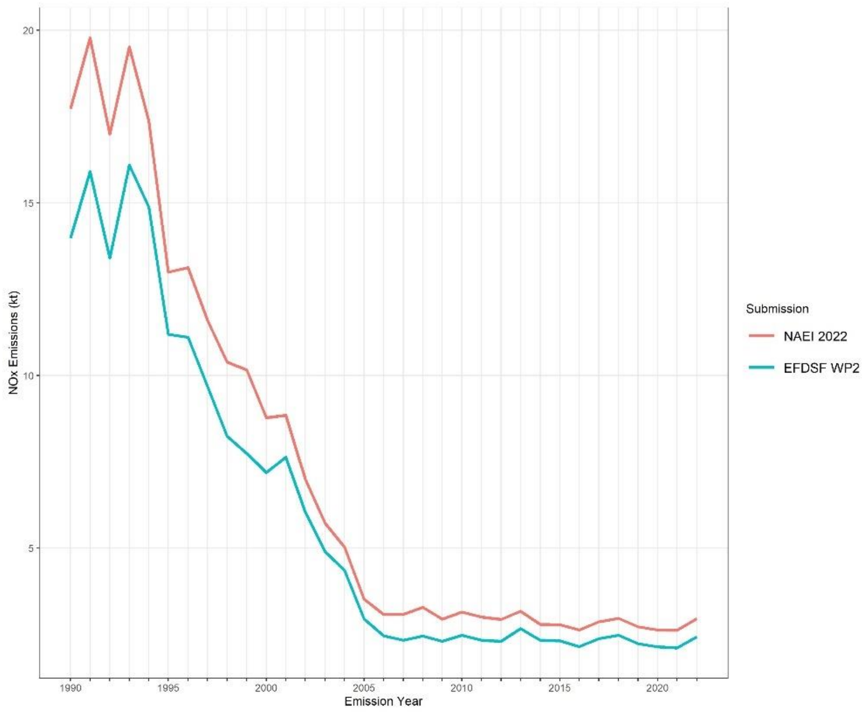


Figure 6-31 Historic impact of new EFs on NO_x emissions in domestic combustion sector

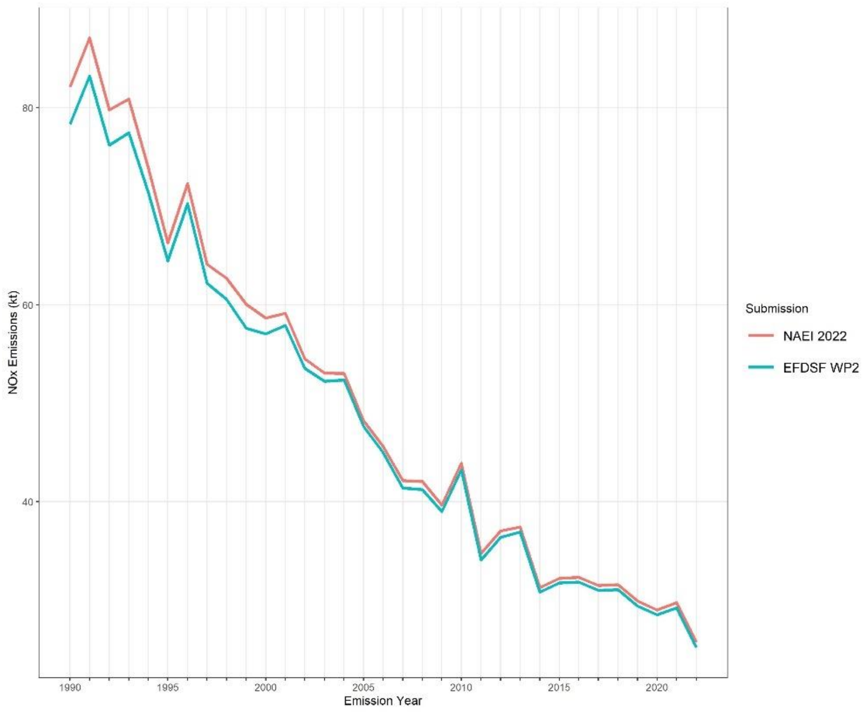
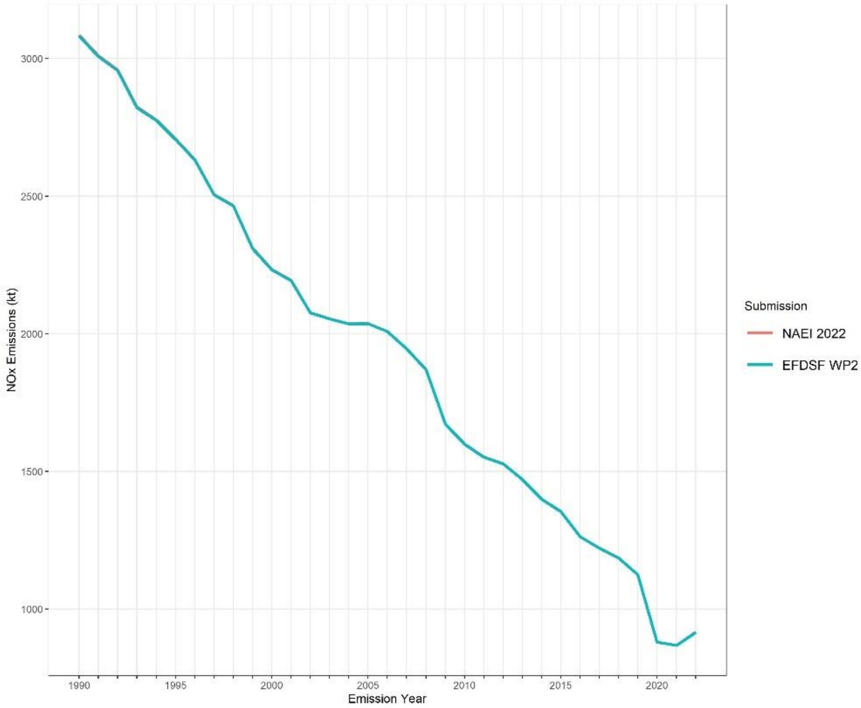


Figure 6-32 Historic impact of new EFs on NO_x emissions in all sectors



Although revision of solid mineral fuel emission factors has a significant impact on NOx emissions attributed to solid mineral fuel, emissions in the residential sector in recent years are dominated by missions from use of other fuels (in particular natural gas use) and the impact of emission factor changes on the national emission is small.

6.3.5 Sulphur dioxide

Figure 6-33 Historic impact of new EFs on SO_2 emissions in domestic combustion (solid mineral fuels) sector

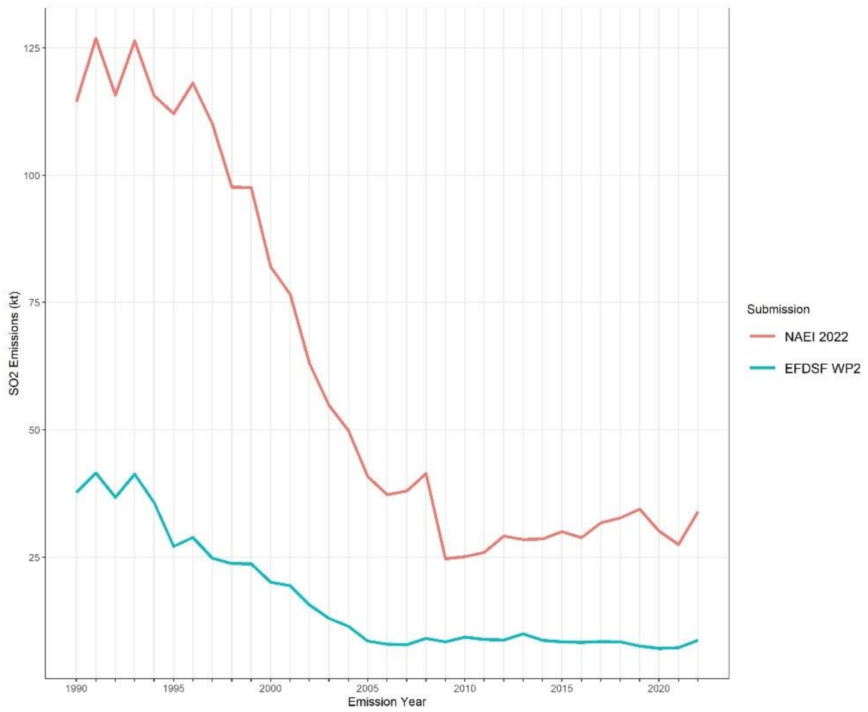


Figure 6-34 Historic impact of new EFs on SO_2 emissions in domestic combustion sector

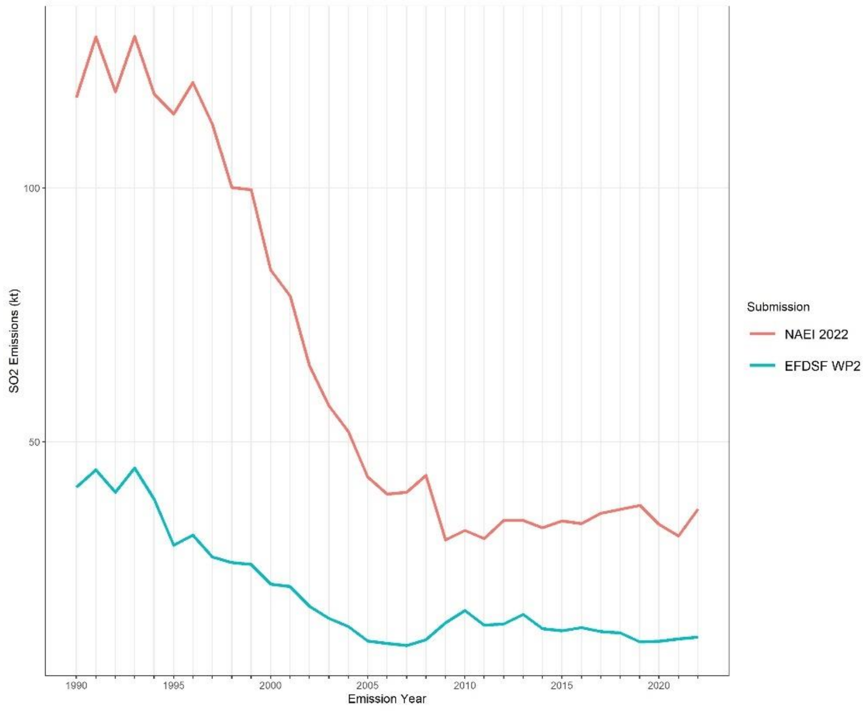
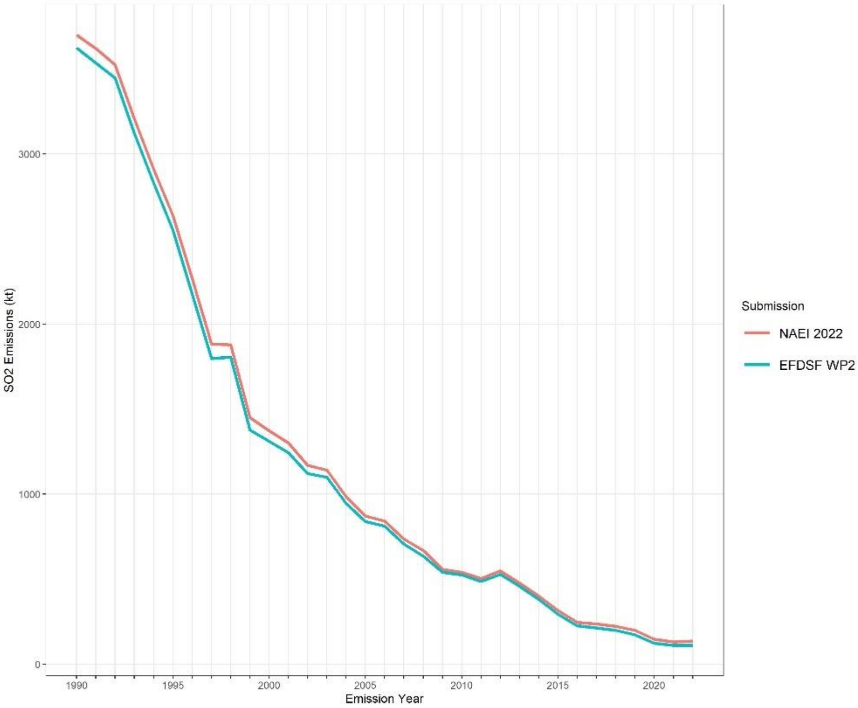


Figure 6-35 Historic impact of new EFs on SO_2 emissions in all sectors



Revision of solid mineral fuel emission factors for SO_2 has a major impact on emissions attributed to solid mineral fuel and residential combustion. Emissions of SO_2 have declined significantly over the timeseries due to increased emission abatement and latterly decarbonisation of the energy sector which has increased the significance of residential combustion in recent years. The impact of emission factor changes on the national totals in recent years is small but significant as residential combustion is one of the key sources. Other sources include non-residential small combustion sources, industry, oil refining and construction.

6.3.6 Dioxins and furans (PCDD/F)

Figure 6-36 Historic impact of new EFs on PCDD/F emissions in domestic combustion (solid mineral fuels) sector

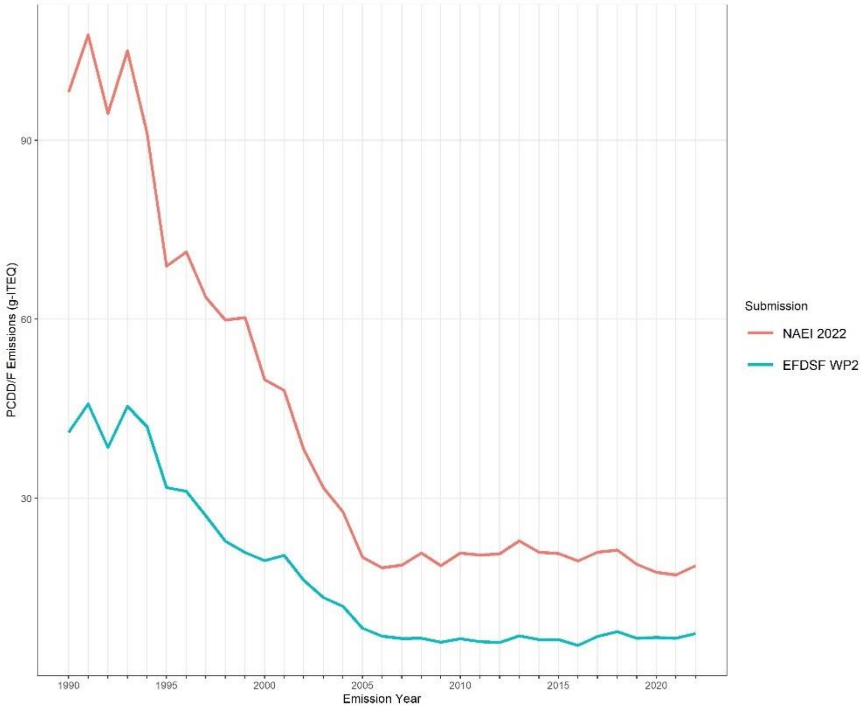


Figure 6-37 Historic impact of new EFs on PCDD/F emissions in domestic combustion sector

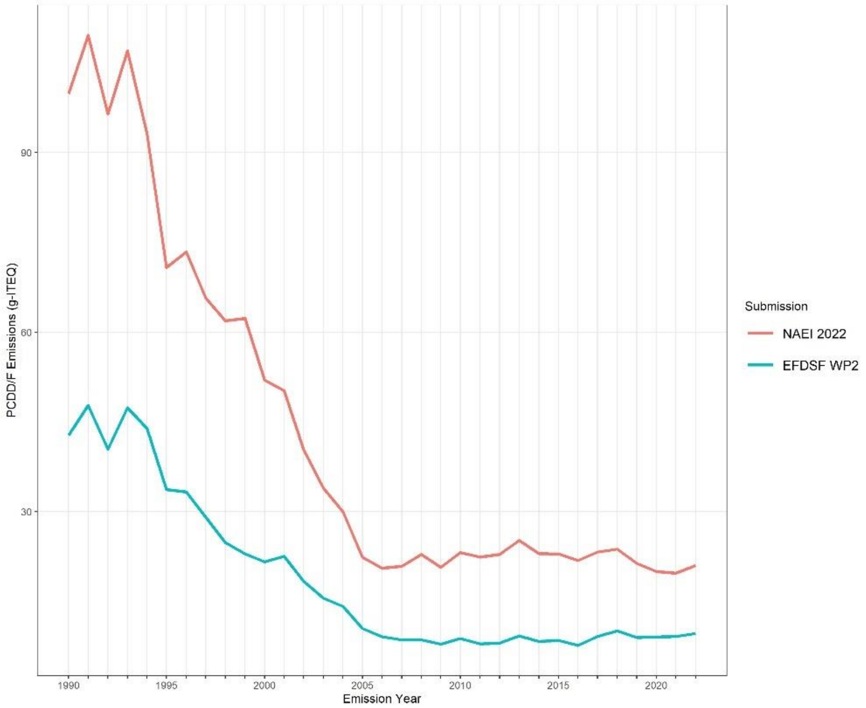
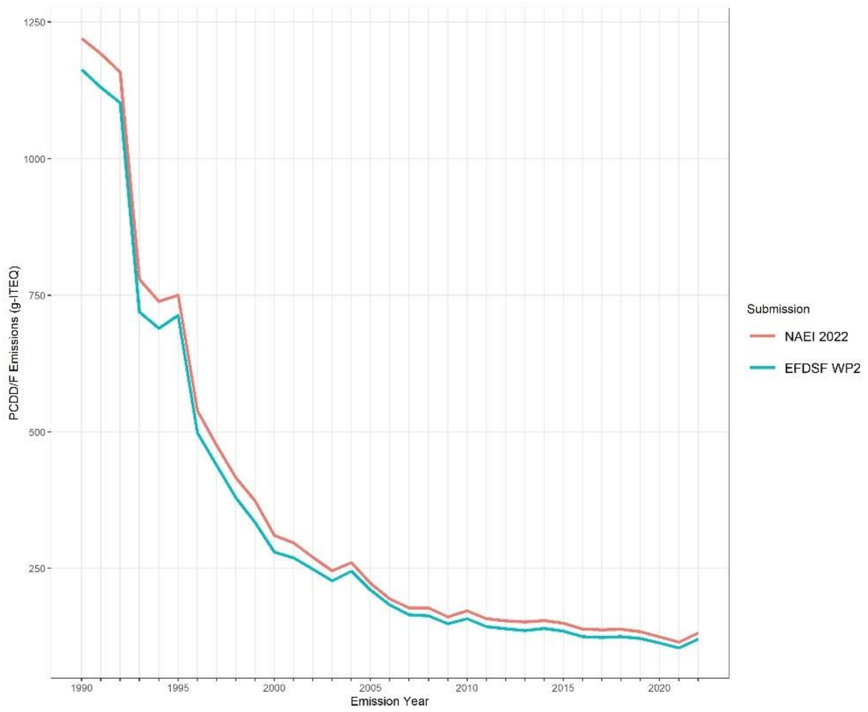


Figure 6-38 Historic impact of new EFs on PCDD/F emissions in all sectors



Revision of solid mineral fuel PCDD/F emission factors has a major impact on emissions attributed to solid mineral fuel across the time series. Residential combustion is a key source for PCDD/F in the NAEI. The contribution of PCDD/F emissions from residential combustion to the national total was 16% in 2022 (other key sources in 2022 include waste activities, iron and steel production and industrial combustion activity) and the impact of revisions to PCDD/F emission factors for residential combustion on the national totals is significant across the timeseries.

6.3.7 PAH (Benzo[a]pyrene)

Figure 6-39 Historic impact of new EFs on total PAH emissions in domestic combustion (solid mineral fuels) sector

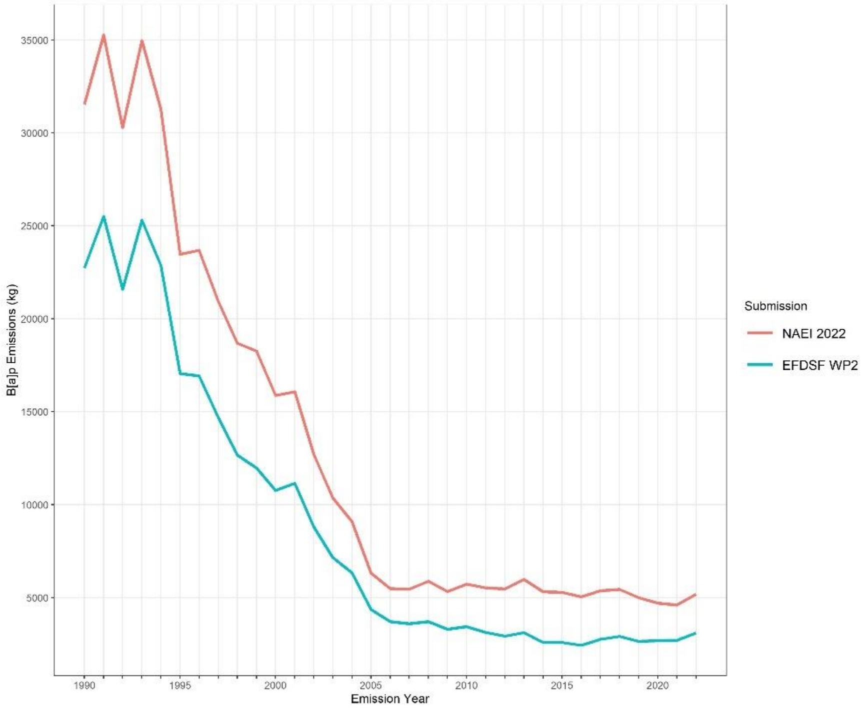


Figure 6-40 Historic impact of new EFs on total PAH emissions in domestic combustion sector

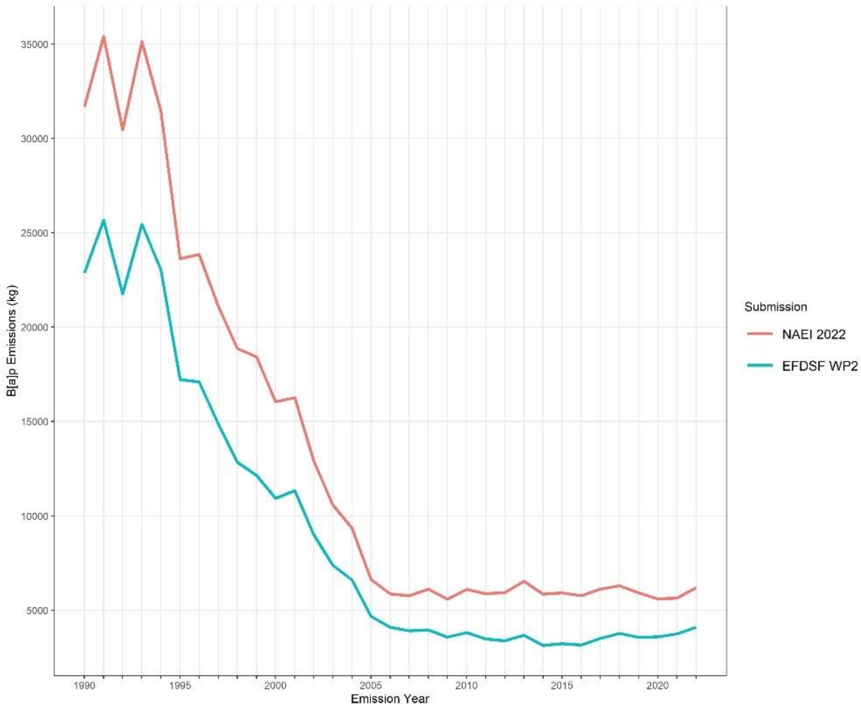
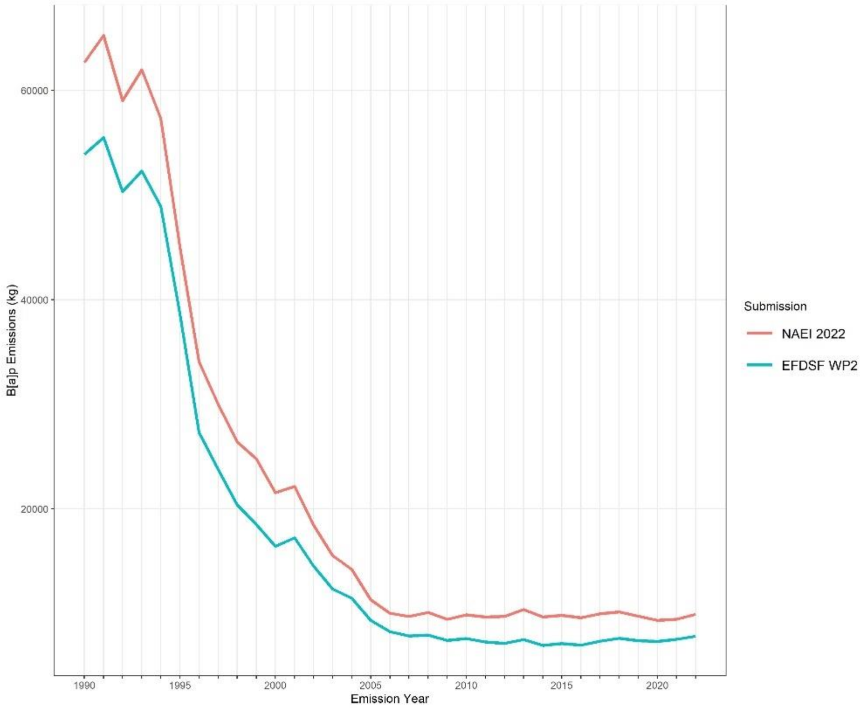


Figure 6-41 Historic impact of new EFs on total PAH emissions in all sectors



Revision of solid mineral fuel PAH emission factors has a major impact on emissions attributed to solid mineral fuel and residential combustion across the time series. Residential combustion is the main source for PAH in the NAEI in 2022 - the contribution of residential combustion to the national total for PAH was 88% in 2022. Consequently, the impact of revisions to PAH emission factors for residential combustion on the national totals is significant.

6.4 INCLUSION OF EFDSF PROJECT EMISSION FACTORS IN THE UK NAEI

6.4.1 Overview

The NAEI uses emission estimation methodologies which are consistent with international guidance on emission inventories and in particular the EMEP/EEA Emission Inventory Guidebook (EIG). The EIG sets out methodologies for activities required for international reporting. Different methodology levels ('Tiers') are applied with higher tier methods providing improved uncertainty but requiring more detailed understanding of the activity. Inventory compilers can improve uncertainty by application of country-specific emission factors and/or higher tier methods, for example more detailed modelling of an activity.

For residential combustion of solid fuels, the NAEI uses estimates of fuels burned at UK-level from UK energy statistics and EIG 'Tier 2' default emission factors which cover several residential heating burning technologies:

- Open fireplace
- Stoves (conventional, high efficiency, advanced/ecolabelled)
- Boilers

The recent Defra Domestic Burning Survey has led to revision of residential energy data for wood-burning and, for all fuels, provided improved understanding of the types of appliances used. A second survey has been undertaken and is expected to report in 2024. The Defra Emission Factors for Domestic Solid Fuel (EFDSF) project has been developed to provide emission factors which can be used with fuel data and, where appropriate, allow application of country-specific emission factors rather than EIG default factors. This is particularly relevant for solid mineral fuels as the EIG factors are for coal whereas UK activity data are available for coal, anthracite and manufactured solid fuel (also petroleum coke and, historically, coke).

The EFDSF project steering group has endorsed the test protocol, appliances tested and the use of selected emission factors.

The EIG emission factors for residential solid fuels (excluding biomass) are predominantly referenced to an earlier (2006) version of the EIG and the original references are unclear. There are also very few recent papers for mineral fuels for appliances or fuels used in European countries (see Annex A.8). The following commentary summarises evidence that the proposed EFs are better than current NAEI default EFs which are drawn from the EIG and other research.

Information on uncertainty has been provided in Section 5.5 and the EFDSF project team is investigating ways to extend the measurement uncertainty to account for the data manipulation/handling operations (including dilution correction, normalisation of concentrations and the conversion of concentrations to emission factor) as well as other approaches to assessing a confidence interval however, there are a range of wider uncertainty factors where quantification is not straightforward and not within the scope of the EFDSF project.

6.4.2 Comparison of EFDSF and Guidebook Tier 2 default emission factor references

The absence of clear references in the EIG makes comparison difficult. It is likely that the features of literature data identified for wood-burning in WP1 also apply to mineral fuels with the addition that EIG emission factors are essentially for older appliances (mainly before 2006).

The NAEI currently uses some country-specific emission factors for certain pollutants from solid mineral fuels including:

- PM emission factors – based on EIG Tier 2 emission factors for coal but with anthracite and solid smokeless fuel (SSF) set at one-fifth of the EIG factor based on dated UK country-specific research on emission limits for Authorised fuels approved for use in Smoke Control Areas under the Clean Air Act 1993.
- SOx – country-specific data for sulphur content but with the reduction in coal use and fewer mines in operation the data are increasingly uncertain.
- NMVOC – EIG Tier 2 emission factors applied to coal but with dated UK country-specific research for manufactured solid mineral fuels.

The evolution of voluntary and mandatory Ecolabels, National and EU Regulatory controls on solid fuel heating appliances means that there are appliances in the market which have different emission characteristics to the range of appliances provided in the EIG. Most recently, the Ecodesign Regulations have set minimum efficiency and emission requirements for solid fuel room heater and boiler products, but all the EIG references are prior to publication of the Ecodesign regulations.

However, it is notable that for the modern appliance using mineral fuels there are higher levels of emissions of CO, PM and TOC/OGC which have emission limits in Ecodesign (and PCDD/F and PAH which are not controlled under Ecodesign) compared to the older appliances. Smaller differences in emission factors will be mitigated by improvement in efficiency for the modern appliance but some differences in emission factors are larger than the likely difference in efficiency.

The EFDSF project test protocol has been designed to reflect use of appliances in the UK including evidence from the Defra Burning Survey on residential burning practise in UK. The test protocols applied for the EIG emission factors are unknown.

- Pollutants – for wood-burning the EIG generally includes several references for each technology type but for mineral fuels the scope of references is unclear. The EFDSF test protocol does not cover all pollutants required for the EIG/NAEI but all EFDSF measurements were undertaken in parallel in the same test cycles and for the same appliance – use of data from different test cycles and appliances is an additional uncertainty which the EFDSF data avoids.
- Appliances – the technology descriptions used in the EIG are broad and references are unclear but clearly predate the EU Ecodesign Regulations for roomheaters and boilers; the potential coverage of EN13240-compliant stoves is also unclear, many references in the EIG may also predate this EN Standard (which is harmonised to the Construction Products Regulation). The EFDSF project included a range of appliances which are consistent with the evolution of appliance design in the UK.

- Range of appliances - the EFDSF project has monitored emissions from only one appliance for each technology type, it is possible that the some EIG Tier 2 emission factors may represent an average of a number of appliances but this is unknown and there are examples from the EIG (for wood-burning) where emission factors have been assigned to a single reference with only a single relevant appliance or, suggesting the emission factor is derived from a single appliance or, indicating an aggregation of emission factors for the different technologies covered in the paper.
- Appliance draught –The draught influences the air supply to the appliance and hence burn rate. In the EFDSF project a draught of 16 Pa based on UK measurements provided by the steering group which is higher than used in EN appliance testing but the draught applied in EIG reference studies is unknown.
- Measurement approaches – the range of measurement approaches applied in EIG references is unknown for solid mineral fuels but, as indicated for wood-burning, is likely to include novel approaches, short-term measurement and semi-continuous monitoring however for EDFDSF we have applied consistent EN or CEN/TS pollutant-specific test methods and accredited testhouses. The EFDSF project has identified where deviations from full compliance with EN approaches has been adopted – primarily to allow fewer sampling systems to avoid practical issues in emission sampling on a small duct.

6.4.3 Conclusion

The references for EIG emission factors for other solid fuels (excluding biomass) are less clear than for wood and are likely for older appliances because they were mainly developed for the 2006 version of the EIG. Consequently, the EFDSF project team considers that the proposed country-specific emission factors:

1. Better represent UK operating practise with respect to burn duration, number of refuels, fuel load, draught and fuel types – these are unknown for the EIG emission factors.
   Aare largely based on three replicate test cycles – the number of replicate tests is unknown for the EIG emission factors.
2. Better represents appliances used in UK:
   a. traditional multifuel open fireplace,
   b. old basic multifuel stove,
   c. old multifuel stove with secondary air (EN13240) and,
   d. a modern ecodesign-compliant stove.
3. Are based on tests for the same appliance and same test cycles for all measured pollutants.
4. Provide data measured by accredited test houses using test approaches which are consistent with EN and CEN/TS approaches for emission measurement.
5. Allow application of emission factors for anthracite and manufactured solid fuels.

7. RECOMMENDATIONS AND CONCLUSIONS

7.1 CONCLUSIONS

Emission factors have been developed for use in the NAEI for coal, anthracite, manufactured solid (mineral) fuels and coffee logs for the four appliance types for PM, $PM_{2.5}$, PM_{10}, NOx, SO_2, CO, NMVOC, PAH, PCDD/F. In addition, condensable PM emission factors have been determined (these are not currently applied in the NAEI as total filterable+condensable emissions are reported).

Further emission factor data has been developed for heavy metals and Black Carbon but are not proposed for inclusion in the NAEI at this stage.

Black Carbon emission factors have been developed in the measurement programme but are for a more limited dataset, with only one measurement taken for each appliance-fuel combination in each phase of the burn cycle (rather than three repeat measurements). In Work Package 3, three repeat measurements will be made for black carbon. This will allow verification of the data collected so far, and the WP2 data will be combined with the WP3 data to produce a black carbon emission factor for each category of appliance.

Heavy metal emission factor measurements indicated some anomalous data for certain metals which have been excluded from the data. The reported emission factors will be considered with further measurements for these pollutants undertaken in Work Package 3.

In general, although substantial changes can be seen for emission estimates from coal, anthracite and manufactured solid fuels, the impact of changes on UK national emissions is generally small. However, the new emission factors for PAH including Benzo(a)pyrene and PCDD/F would result in a significant reduction in national emissions.

The proposed country-specific emission factors are an improvement on current emission factors used by the NAEI because they:

- Better represent UK operating practise with respect to burn duration, number of refuels, fuel load, draught and the types of solid mineral fuels used in the UK.
- Are based on three replicate test cycles.
- Better represents appliances used in the UK.
- Are based on tests for the same appliance and the same test cycles for measured pollutants.
- Provide data measured by accredited test houses using test approaches that are consistent with EN and CEN/TS approaches for emission measurement.

It is notable that for the modern Ecodesign appliance using mineral fuels that there are higher emission factors for CO, PM and TOC/OGC (which have emission limits in the Ecodesign Regulation) and PCDD/F and PAH compared to the older appliances. Smaller differences in emission factors will be mitigated by higher energy efficiency for the modern appliance but elevated emission factors are often higher than could be offset by improved energy efficiency.

7.2 RECOMMENDATIONS

The following recommendations are made:

1. To include the emissions factors for PM, $PM_{2.5}$, PM_{10}, NOx, SO_2, CO, NMVOC, PAH, PCDD/F in the next submission of the NAEI (2025).
2. To delay incorporation of the heavy metal and Black Carbon emission factors into the NAEI until completion and review of the Work Package 3 testing.
3. To investigate establishment of activity data to allow adoption of emission factors for coffee logs to be included in the NAEI if similar fuels are commercially available (the original manufacturer has ceased trading).
4. To consider similar testing programmes for to represent a wider range of appliances including new appliance types and emerging fuels.

5. To consider further testing on modern Ecodesign appliances to understand why emissions of certain pollutants appear to be elevated compared to older technologies.
6. To consider sensitivity testing of emission parameters to (for example) different lighting practises, inclusion of fines in fuel mix.
7. To consider alternatives to emission monitoring for determination of heavy metals (fuel and ash analysis).

APPENDICES

A.1 FUEL ANALYSIS

Table A-1 Summary of WP2 Fuel Analysis by an Independent Testing House

Component	Units	Heat Approved	Superheat	Coal	Anthracite	Coffee logs
CV, net	MJ/kg	24.995	28.007	26.273	32.591	18.26
Moisture	% m/m	20.2	7.0	10.3	1.9	8.3
Ash	% m/m	3.8	4.6	1.3	3.6	0.8
C	% m/m	63.90	73.40	68.10	88.10	47.20
H	% m/m	3.13	3.93	4.71	3.62	6.02
N	% m/m	1.05	1.16	1.11	1.03	1.45
S	% m/m	1.36	2.35	0.18	0.75	0.04
Volatile matter (VM)	% m/m	14.2	22.2	39.9	6.6	74.6
O (by diff)	% m/m	6.56	7.56	14.30	1.00	36.19
Fixed Carbon (by diff)	% m/m	61.8	66.2	48.5	87.9	16.3
Calculated dry flue gas volume, 0% O_2	m^3/GJ (0°C, 101.3 kPa, net heat input)	249	259	255	264	248

Fuel was analysed by Alfred H Knight Energy Services Limited
All analysis data is on as received basis (see analysis sheets for other reporting)

Figure A-1 Certificate of Analysis for Heat Approved

CERTIFICATE OF ANALYSIS

ORIGINAL

ALFRED H KNIGHT

JON FREEMAN
KIWA UK
KIWA HOUSE
MALVERN VIEW BUSINESS PARK
STELLA WAY
BISHOPS CLEEVE
CHELTENHAM
GL52 7DQ

Test Date(s): 14-Jun-2022 to 15-Jun-2022
Date of Report: 15-Jun-2022

Date Received: 14-Jun-2022

AHK Ref: DC/388141
Client Ref: PROJECT NUMBER - 31153

Material Described As: COAL

Samples were received by Alfred H Knight Energy Services Ltd and analysis results relate only to the items tested.

Client Ref.	Test	Unit	As Received	Dry Basis	Dry Ash-Free
1787/1					
	Total Moisture	%	20.2		
	Analysis Moisture	%	1.93		
	Ash Content	%	3.8	4.8	
	Volatile Matter	%	14.2	17.8	18.7
	Total Sulphur	%	1.36	1.71	1.80
	Carbon	%	63.9	80.1	84.1
	Hydrogen	%	3.13	3.92	4.12
	Nitrogen	%	1.05	1.31	1.38
	Oxygen By Difference	%	6.5	8.2	8.6
	Gross Calorific Value	KCal/Kg	6231	7808	8202
	Gross Calorific Value	MJ/Kg	26.088	32.692	34.340
	Net Calorific Value	KCal/Kg	5970		
	Net Calorific Value	MJ/Kg	24.995		

AHK ENERGY SERVICES ALFRED H KNIGHT INTERNATIONAL INSPECTORS OF COAL AND BIOFUELS

Fiona Main

For and on behalf of Alfred H Knight Energy Services Ltd

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CERTIFICATE OF ANALYSIS

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Test Date(s): 14-Jun-2022 to 15-Jun-2022
Date of Report: 15-Jun-2022

Date Received: 14-Jun-2022

AHK Ref: DC/388141
Client Ref: PROJECT NUMBER - 31153

Material Described As: COAL

Samples were received by Alfred H Knight Energy Services Ltd and analysis results relate only to the items tested.

Client Ref.	Test	Unit	As Received	Dry Basis	Dry Ash-Free
1787/1					
	TRACE METAL ANALYSIS				
	Cadmium	mg/Kg		0.04	
	Zinc	mg/Kg		10.47	
	Vanadium	mg/Kg		171.22	
	Lead	mg/Kg		6.28	
	Copper	mg/Kg		14.42	
	Chromium	mg/Kg		11.79	
	Nickel	mg/Kg		61.13	
	Antimony	mg/Kg		0.69	
	Cobalt	mg/Kg		4.17	
	Manganese	mg/Kg		44.45	
	Thallium	mg/Kg		250.13	
	Arsenic	mg/Kg		2.01	
	Mercury	mg/Kg		0.11	
	Tin	mg/Kg		0.27	

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Figure A-2 Certificate of Analysis for Superheat

CERTIFICATE OF ANALYSIS

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GL52 7DQ

Test Date(s): 14-Jun-2022 to 15-Jun-2022
Date of Report: 15-Jun-2022

Date Received: 14-Jun-2022

AHK Ref: DC/388141
Client Ref: PROJECT NUMBER - 31153

Material Described As: COAL

Samples were received by Alfred H Knight Energy Services Ltd and analysis results relate only to the items tested.

Client Ref.	Test	Unit	As Received	Dry Basis	Dry Ash-Free
1787/2					
	Total Moisture	%	7.0		
	Analysis Moisture	%	2.25		
	Ash Content	%	4.6	4.9	
	Volatile Matter	%	22.2	23.9	25.1
	Total Sulphur	%	2.35	2.53	2.66
	Carbon	%	73.4	78.9	83.0
	Hydrogen	%	3.93	4.23	4.45
	Nitrogen	%	1.16	1.25	1.31
	Oxygen By Difference	%	7.6	8.2	8.6
	Gross Calorific Value	KCal/Kg	6921	7442	7825
	Gross Calorific Value	MJ/Kg	28.979	31.160	32.766
	Net Calorific Value	KCal/Kg	6689		
	Net Calorific Value	MJ/Kg	28.007		

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CERTIFICATE OF ANALYSIS

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GL52 7DQ

Test Date(s): 14-Jun-2022 to 15-Jun-2022
Date of Report: 15-Jun-2022

Date Received: 14-Jun-2022

AHK Ref: DC/388141
Client Ref: PROJECT NUMBER - 31153

Material Described As: COAL

Samples were received by Alfred H Knight Energy Services Ltd and analysis results relate only to the items tested.

Client Ref.	Test	Unit	As Received	Dry Basis	Dry Ash-Free
1787/2					
	TRACE METAL ANALYSIS				
	Cadmium	mg/Kg		0.06	
	Zinc	mg/Kg		12.24	
	Vanadium	mg/Kg		245.38	
	Lead	mg/Kg		3.26	
	Copper	mg/Kg		7.03	
	Chromium	mg/Kg		13.37	
	Nickel	mg/Kg		89.80	
	Antimony	mg/Kg		0.46	
	Cobalt	mg/Kg		3.35	
	Manganese	mg/Kg		62.13	
	Thallium	mg/Kg		130.33	
	Arsenic	mg/Kg		1.38	
	Mercury	mg/Kg		0.03	
	Tin	mg/Kg		0.21	

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Figure A-3 Certificate of Analysis for Anthracite Small Nuts

CERTIFICATE OF ANALYSIS

ORIGINAL

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GL52 7DQ

Test Date(s): 14-Jun-2022 to 15-Jun-2022
Date of Report: 15-Jun-2022

Date Received: 14-Jun-2022

AHK Ref: DC/388141
Client Ref: PROJECT NUMBER - 31153

Material Described As: COAL

Samples were received by Alfred H Knight Energy Services Ltd and analysis results relate only to the items tested.

Client Ref.	Test	Unit	As Received	Dry Basis	Dry Ash-Free
1787/3					
	Total Moisture	%	1.9		
	Analysis Moisture	%	1.04		
	Ash Content	%	3.6	3.7	
	Volatile Matter	%	6.6	6.7	7.0
	Total Sulphur	%	0.75	0.76	0.79
	Carbon	%	88.1	89.8	93.3
	Hydrogen	%	3.62	3.69	3.83
	Nitrogen	%	1.03	1.05	1.09
	Oxygen By Difference	%	1.0	1.0	1.0
	Gross Calorific Value	KCal/Kg	7976	8130	8442
	Gross Calorific Value	MJ/Kg	33.391	34.038	35.346
	Net Calorific Value	KCal/Kg	7784		
	Net Calorific Value	MJ/Kg	32.591		

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Fiona Main

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CHELTENHAM
GL52 7DQ

Test Date(s): 14-Jun-2022 to 15-Jun-2022
Date of Report: 15-Jun-2022

Date Received: 14-Jun-2022

AHK Ref: DC/388141
Client Ref: PROJECT NUMBER - 31153

Material Described As: COAL

Samples were received by Alfred H Knight Energy Services Ltd and analysis results relate only to the items tested.

Client Ref.	Test	Unit	As Received	Dry Basis	Dry Ash-Free
1787/3					
	TRACE METAL ANALYSIS				
	Cadmium	mg/Kg		0.04	
	Zinc	mg/Kg		10.65	
	Vanadium	mg/Kg		14.07	
	Lead	mg/Kg		7.25	
	Copper	mg/Kg		21.93	
	Chromium	mg/Kg		12.19	
	Nickel	mg/Kg		33.41	
	Antimony	mg/Kg		0.55	
	Cobalt	mg/Kg		18.65	
	Manganese	mg/Kg		22.50	
	Thallium	mg/Kg		129.50	
	Arsenic	mg/Kg		2.20	
	Mercury	mg/Kg		0.06	
	Tin	mg/Kg		0.22	

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ALFRED H KNIGHT
INTERNATIONAL INSPECTORS OF COAL AND BIOFUELS

Fiona Main

For and on behalf of Alfred H Knight Energy Services Ltd

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Figure A-4 Certificate of Analysis for Coal Trebles

CERTIFICATE OF ANALYSIS

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KIWA HOUSE
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STELLA WAY
BISHOPS CLEEVE
CHELTENHAM
GL52 7DQ

Test Date(s): 14-Jun-2022 to 15-Jun-2022
Date of Report: 15-Jun-2022

Date Received: 14-Jun-2022

AHK Ref: DC/388141
Client Ref: PROJECT NUMBER - 31153

Material Described As: COAL

Samples were received by Alfred H Knight Energy Services Ltd and analysis results relate only to the items tested.

Client Ref.	Test	Unit	As Received	Dry Basis	Dry Ash-Free
1787/5					
	Total Moisture	%	10.3		
	Analysis Moisture	%	6.48		
	Ash Content	%	1.3	1.5	
	Volatile Matter	%	39.9	44.5	45.2
	Total Sulphur	%	0.18	0.20	0.20
	Carbon	%	68.1	75.9	77.1
	Hydrogen	%	4.71	5.25	5.33
	Nitrogen	%	1.11	1.24	1.26
	Oxygen By Difference	%	14.3	15.9	16.1
	Gross Calorific Value	KCal/Kg	6567	7321	7432
	Gross Calorific Value	MJ/Kg	27.493	30.650	31.117
	Net Calorific Value	KCal/Kg	6275		
	Net Calorific Value	MJ/Kg	26.273		

AHK ENERGY SERVICES ALFRED H KNIGHT INTERNATIONAL INSPECTORS OF COAL AND BIOFUELS

Fiona Main

For and on behalf of Alfred H Knight Energy Services Ltd

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CHELTENHAM
GL52 7DQ

Test Date(s): **14-Jun-2022 to 15-Jun-2022**
Date of Report: **15-Jun-2022**

Date Received: 14-Jun-2022

AHK Ref: DC/388141
Client Ref: PROJECT NUMBER - 31153

Material Described As: COAL

Samples were received by Alfred H Knight Energy Services Ltd and analysis results relate only to the items tested.

Client Ref.	Test	Unit	As Received	Dry Basis	Dry Ash-Free
1787/5					
	TRACE METAL ANALYSIS				
	Cadmium	mg/Kg		0.02	
	Zinc	mg/Kg		5.87	
	Vanadium	mg/Kg		1.68	
	Lead	mg/Kg		0.82	
	Copper	mg/Kg		5.72	
	Chromium	mg/Kg		2.62	
	Nickel	mg/Kg		3.86	
	Antimony	mg/Kg		0.10	
	Cobalt	mg/Kg		0.96	
	Manganese	mg/Kg		10.26	
	Thallium	mg/Kg		107.02	
	Arsenic	mg/Kg		0.58	
	Mercury	mg/Kg		0.01	
	Tin	mg/Kg		0.03	

AHK ENERGY SERVICES ALFRED H KNIGHT

Fiona Main

For and on behalf of Alfred H Knight Energy Services Ltd

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Figure A-5 Certificate of Analysis for Coffee Logs

CERTIFICATE OF ANALYSIS

JASON POWIS
KIWA UK
KIWA HOUSE
MALVERN VIEW BUSINESS PARK
STELLA WAY
BISHOPS CLEEVE
CHELTENHAM
GL52 7DQ

Date Received: 03-Oct-2022

Test Date(s): **03-Oct-2022 to 11-Oct-2022**
Date of Report: **11-Oct-2022**

AHK Ref: **DB/391654**
Client Ref: **PROJECT NUMBER - 31153**

Material Described As: WOOD LOGS

Samples were received by Alfred H Knight Energy Services Ltd and analysis results relate only to the items tested.

Client Ref.	Test	Unit	As Received	Dry Basis	Dry Ash-Free
1800-1 Coffee Logs					
	Free Moisture	%	4.3		
	Total Moisture	%	8.3		
	Ash Content	%	0.8	0.9	
	Volatile Matter	%	74.6	81.4	82.1
	Total Sulphur	%	0.04	0.04	0.04
	Carbon	%	47.2	51.5	52.0
	Hydrogen	%	6.02	6.57	6.63
	Nitrogen	%	1.45	1.58	1.59
	Oxygen By Difference	%	36.1	39.4	39.8
	Gross Calorific Value	MJ/Kg	19.770	21.559	21.755
	Net Calorific Value	MJ/Kg	18.260		

Scott Foster
Biomass Operations Manager
For and on behalf of Alfred H Knight Energy Services Ltd

Doc Id: DB/391654/1 **Alfred H Knight Energy Services Ltd** Page 1 of 2

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CERTIFICATE OF ANALYSIS

JASON POWIS
KIWA UK
KIWA HOUSE
MALVERN VIEW BUSINESS PARK
STELLA WAY
BISHOPS CLEEVE
CHELTENHAM
GL52 7DQ

Date Received: 03-Oct-2022

Test Date(s): 03-Oct-2022 to 11-Oct-2022
Date of Report: 11-Oct-2022

AHK Ref: DB/391654
Client Ref: PROJECT NUMBER - 31153

Material Described As: WOOD LOGS

Samples were received by Alfred H Knight Energy Services Ltd and analysis results relate only to the items tested.

Client Ref.	Test	Unit	As Received	Dry Basis	Dry Ash-Free
1800-1 Coffee Logs					
	TRACE METAL ANALYSIS				
	Cadmium	mg/Kg		0.07	
	Zinc	mg/Kg		452.13	
	Vanadium	mg/Kg		0.70	
	Lead	mg/Kg		7.29	
	Copper	mg/Kg		13.68	
	Chromium	mg/Kg		3.25	
	Nickel	mg/Kg		2.70	
	Antimony	mg/Kg		0.19	
	Cobalt	mg/Kg		0.27	
	Manganese	mg/Kg		41.74	
	Thallium	mg/Kg		< 0.10	
	Arsenic	mg/Kg		0.55	
	Mercury	mg/Kg		0.02	
	Tin	mg/Kg		0.18	
	Selenium	mg/Kg		< 0.10	
	Titanium	mg/Kg		50.18	

Scott Foster
Biomass Operations Manager
For and on behalf of Alfred H Knight Energy Services Ltd

Doc Id: DB/391654/1

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A.2 STOVE SPECIFICATIONS

Charnwood C-4 blu – Modern Stove

charnwood

C-FOUR *blu*

Featuring a large picture window the C-Four is the smallest model in the C-Series delivering a heat output to the room of between 2 to 5.5kW. The stove is steel plate lined and can take a log length of up to 282mm (11"). With a rated output of 4.9kW the C-Four, in certain situations, can be installed without the need for external air. This model is SIA Ecodesign ready (blu).

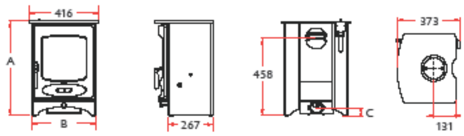
RATED OUTPUT
4.9kW to room (range 2-5.5kW)

NET EFFICIENCY
82%

FLUE OUTLET
Top or Rear 125mm (5") dia

MAX LOG LENGTH
282mm (11")

MIN DISTANCE TO COMBUSTIBLES
Side: 500mm Rear: 370mm With heatshield - Rear: 175mm



		A	B	C	WEIGHT
LOW LEGS		560	386	45	83KG
STORE STAND		710	386	195	89KG
HIGH LEGS		765	400	248	85.5KG

Dovre 500MRF Cast Iron Stove

Dovre 500MFR/500MFF Cast Iron Stove Installation and Operating Manual

Before commencing with the installation it is important that these instructions are read and fully understood.

When installing the model Dovre 500MFF, follow the installation and operating instructions for the MFR with the following exceptions:

1 ***PAGE 1, ASSEMBLY SECTION 5***
Ignore this instruction which applies only to the model Dovre 500 MFR

2 ***DIAGRAM Fig 5***
Ignore this diagram which refers to the grate system incorporated in the model 500MFR

3 ***DIAGRAM fig 6***
The sketch illustrates the riddling rod which is not applicable to the 500MFF

4 ***PAGE 5, ASH REMOVAL - SECTION 3***
The Dovre MFF is not equipped with a riddling grate mechanism and therefore ashes must be removed from the grate using a conventional poker.

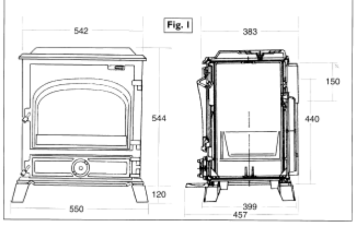


Fig. 1

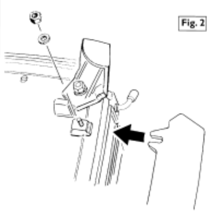


Fig. 2

NOTE: The Dovre 500MFF is the same in all aspects as the 500MFR except for the grate system. The 500MFF is fitted with a one piece cast iron grate suitable to use with wood or smokeless solid fuel. The 500MFF does not incorporate a riddling grate system.

The 500 MFR is a specially designed stove for burning wood and most smokeless fuels. It is essential that when wood is used, it is well-seasoned (min 2 years) and has a maximum moisture content of 20%. If unseasoned wood is used, heat outputs will not be obtained and serious damage will occur in the chimney and flueways.

The dimensions of your new stove are illustrated in fig. 1. Be careful to ensure that your fireplace is going to accept the appliance and that you have allowed for 30cm of hearth space in front of the stove.

REGULATIONS

It is important that the installation is carried out in compliance with current Building Regulations.

1 ASSEMBLY

As the Dovre 500MFR is constructed from heavy cast iron, it is advisable for two people to assemble and position the appliance.

1. Open the stove door and remove all loose parts within.
2. Lay the stove on its back and fit the 4 legs and front ash lip. See fig.2.
3. Fit the circular cast iron flue collar. This can be fitted in one of two positions (see fig.3). For a top flue connection, attach the circular cast iron collar to the aperture located at the top of the appliance, using the nuts, bolts and washers supplied. Use a small amount of fire cement to ensure an air tight seal before fixing. For a rear flue connection, adopt the same procedure using the rear aperture. Fit the cast iron circular cover plate to the unused aperture again using a small amount of fire cement as a seal. The cover plate is attached using the fixing bar and nuts and bolts supplied.
4. Carefully position the stove on the hearth.
5. Fit the solid fuel grate, cradle and riddling arm. See fig.5 page 3

2

2 INSTALLATION

HEARTH REQUIREMENT
The positioning of the appliance and the size and type of hearth are governed by Building Regulations for Class 1 appliances. The Building Regulations state that the hearth must extend at least 30cms to the front of the appliance and 15cms to the sides. If in doubt, expert advice should be sought from your local Building Inspector.

3 CONNECTION TO CHIMNEY

If an existing masonry chimney is installed, the appliance should be connected to the chimney using 150mm diameter 316 grade 1mm stainless steel, cast iron or good quality vitreous enamel flue pipe. It is important to ensure that the connection to the chimney is carried out in such a way that any soot particles are allowed to fall unhindered back into the appliance or flue T-section. See fig.4.

4 ACCESS FOR SWEEPING CHIMNEY

The chimney should be checked and swept at least once a year and it is important to allow provision for gaining access to the chimney. On masonry chimneys, a standard soot door, obtainable from your Dovre dealer, can be used. On other factory made chimneys, it is important to ensure an access cleaning door is provided. It is advisable to ensure that the connecting flue pipe to the chimney has an access door fitted. An access door close to the appliance will also facilitate the use of a chimney vacuum cleaner to ensure clean appliance maintenance.

5 THE CHIMNEY

The chimney must be in good condition and free from cracks and blockages. If the existing chimney is unlined, it is advisable to install a flue liner suitable for use with Class I appliances, with an internal diameter between 150mm and 200mm. Your Dovre dealer can advise further on this subject.
The chimney is responsible for ensuring that flue gases and smoke are taken away from the appliance.

IF THE APPLIANCE EMITS SMOKE INTO YOUR ROOM, IT IS NOT THE FAULT OF THE APPLIANCE. THERE WILL EITHER BE A STRUCTURAL FAULT OR DESIGN FAULT IN THE CHIMNEY OR LACK OF VENTILATION IN THE ROOM.

If an existing chimney is not available, it is possible to install a prefabricated factory chimney system. Your Dovre dealer will provide further information.
It is important to ensure that the chimney structure and design comply with Current Building Regulations for Class I appliances.

THE MINIMUM DRAUGHT REQUIREMENT FOR THE DOVRE 500MFR IS .06" WATER GAUGE.

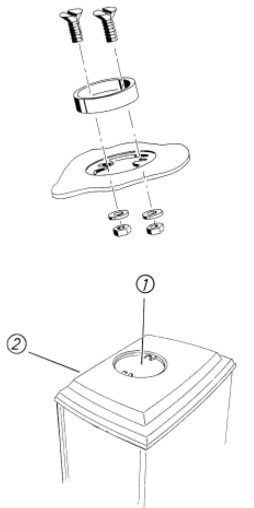


Fig. 3

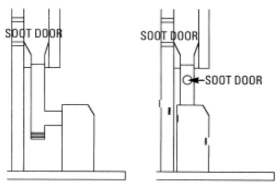


Fig. 4

3

5 THE CHIMNEY (Continued)

Too much draught will cause excessive heat outputs and fuel consumption. Inadequate draught may cause smoke emission to the room and poor combustion resulting in a build up of tar and creosote deposits on the glass, inside walls of the appliance and the chimney.

6 OPERATION

The most important factor for avoiding problems with any stove is to prevent the formation of tar and creosote build up.

IF UNSEASONED WOOD IS USED YOUR APPLIANCE MAY NOT FUNCTION CORRECTLY

HOW TAR IS FORMED

A build up of tar within the stove and/or chimney is caused by burning wood and very low temperatures i.e. burnt slowly. The condition is much worse if the wood is not seasoned properly and contains a high moisture content. If the fire is burned at low temperature, the chimney will be cold. Cold chimneys do not work and difficulty occurs with the cold chimney trying to expel the flue gases and smoke. As a result the gases condense on the walls of the chimney and appliance and become creosote or tar.

Creosote build up is dangerous and most chimney fires are caused as a result.

IT IS ESSENTIAL TO USE WELL-SEASONED WOOD OR QUALITY SMOKELESS FUEL AT ALL TIMES.

7 LIGHTING THE STOVE

Woodburning

Ensure that both the air control wheel and top secondary air control lever are in the fully open position. See fig 6.
Lay a few firelighters (or old newspaper) on the base of the stove. Light the fire and close the door. For the first few minutes, it is advisable not to close the door completely. Leave the door 1 or 2cms from the fully closed position until the fire is blazing brightly, then close the door fully. It is important to heat up the chimney quickly, so ensure that a good hot fire bed is established before adding further fuel.

Smokeless Fuel

Carry out the same procedure as above but do not open the top secondary air control lever. When burning smokeless fuel, this lever should always be in the closed position.

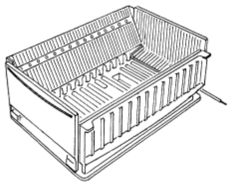


Fig. 5

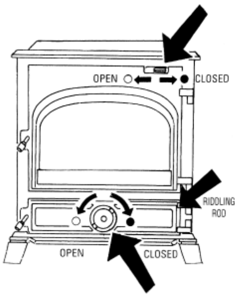


Fig. 6

4

8 ADDING FUEL

Your wood should ideally be 35 to 38cms in length with a diameter of between 5 and 10 cms.

It is good practice, before adding fuel, to separate the ashes from the hot wood embers. To do this, use a fireplace scraper tool to push the ashes to the rear of the stove close to the air inlet. This will help to ensure a faster response with the combustion. When adding fuel, load two or three logs of the dimensions given above, close the door and fully open the lower top air controls, see fig 6.

9 ADJUSTING HEAT OUTPUT

Once the fire has been well established, you can reduce the burning rate by closing the bottom air control wheel (fig. 6). Start by closing the wheel a little at a time. With experience, you will soon find the best positions most suited to your own installation. The top secondary lever should be left in the open position for woodburning except when overnight burning is required. The air settings will vary on different installations, depending on the type of wood being used and the draught the chimney is able to produce.
When using solid fuel, once a hot bed is established, load small quantities of fuel at a time. Use a coal hod and fireplace shovel for convenience in loading. To control the heat output in your Dovre 500MFR, adjust the bottom air spinning wheel to the required setting. THE TOP AIR INLET SHOULD BE IN THE CLOSED POSITION WHEN BURNING SMOKELESS FUELS.

During the first few hours of use, your stove may give off an unpleasant odour as the high temperature paint is cured. This is normal, so don't be alarmed as the condition only occurs during the first period of use.

10 ASH REMOVAL

When removing the ashes from a hot fire bed, try to ensure that some of the hot embers remain in the stove as this will facilitate re-lighting.

NEVER LET THE ASHPAN OVERFILL.

There should always be a good air space between the top of the ashpan and the underside of the grate. Failure to do this will cause premature deterioration of the grate and will make it difficult to empty the ashpan. Your Dovre 500MFR is equipped with a special grate mechanism which allows ashes to be riddled into the ashpan whilst the stove door is closed. The riddling control lever is situated on the right hand side of the front of the stove above the ashpit door. Gently move the lever backwards and forwards to clear the grate of ash.
To remove the ashpan, see fig 7, open the ashpit door and carefully remove the ashpan using the handle tool provided. Ashes must be disposed of carefully and it is a good idea to purchase an ash carrying box for this purpose. Your Dovre dealer will normally be able to supply a suitable ashpan carrier box.
After replacing the empty ashpan in the ashpit compartment, ensure the ashpit door is fully closed.

11 MANAGING YOUR WOOD SUPPLIES

If you are buying wood from a log merchant, try to ensure that the wood has been seasoned for at least 2 years. 3 years is even better. The wood should preferably be cut to lengths of 35 to 38cms and split to a width of between 5 and 10cms. Store your wood under cover to protect from rain but ideally the wood should be stored in. a place where the wind will be allowed to freely ventilate the stack.
Try to obtain hardwoods such as oak, elm, beech or ash. These woods will provide more calorific value per cubic meter than softwoods.

12 TYPES OF SUITABLE SOLID FUEL

Almost all types of smokeless fuels can be used on your 500MFR.
However, avoid the use of petroleum coke.
Anthracite medium or large nuts is an excellent fuel for good heat output but it is somewhat difficult to get started.

NEVER USE HOUSE COAL (BITUMINOUS COAL) ON THE DOVRE 500MFR

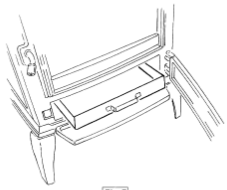


Fig. 7

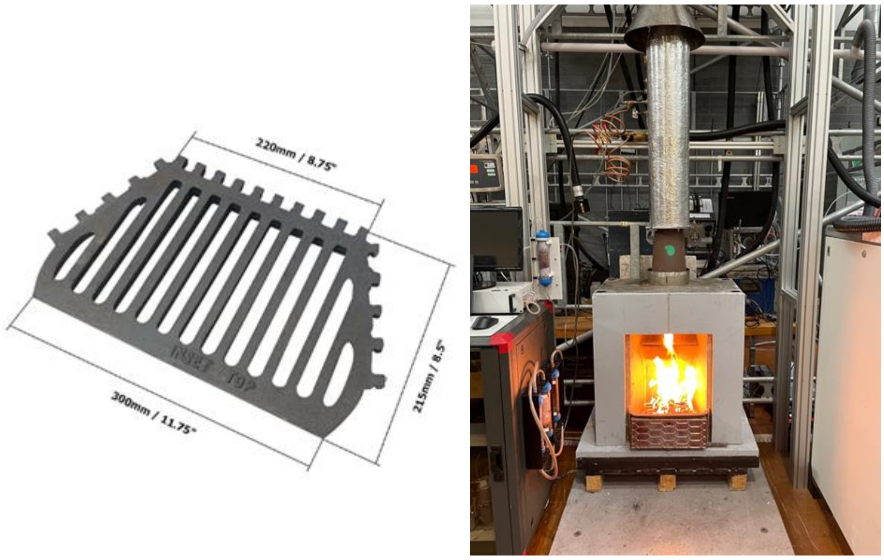
5

Hunter Oakwood Stove

Specification for the Hunter Oakwood stove (Figure A-6) is not available, we believe it is a 1997 model and as per manufacturer's instructions the turbo baffle system was blocked for the test programme.

Figure A-6 Images of the Hunter Oakwood Stove used in the test programme

Figure A-7 Images of the Parkray Paragon 16 inch Fire Grate (Open Fire) used in the test programme



A.3 POLLUTANT MEASUREMENTS DATASET

Table A-2 : Charnwood C-4 blu – Modern Stove test results – COAL

Pollutant + Method	Measurement location	Run 1	Run 2	Run 3	Average	NAEI
CO (Dry, weighted) g/GJ	Appliance outlet	3197	4285	3139	3540	2000
CO_2 (Dry, weighted) g/GJ	Appliance outlet	76387	76131	75220	75912	-
NO_x (Dry, weighted) g/GJ	Appliance outlet	110	95	120	109	150
HC (ECL Dry, weighted) g/GJ	Dilution tunnel	465	480	509	485	-
PM (AO) g/GJ	Appliance outlet	51	47	53	50	-
PM (DT) g/GJ	Dilution tunnel	77	106	105	96	250
Dioxins & Furans nqTEQ/GJ	Dilution tunnel	1064	548	1906	1173	500
PAH's mg/GJ	Dilution tunnel	3787	5354	6972	5371	-
SO_2 g/GJ	Dilution tunnel	203	362	217	261	708
Condensable PM g/GJ	Dilution tunnel	26	59	52	46	720
Total PM, g/GJ	Dilution tunnel	65	45	151	87	250
PM_{10}, g/GJ	Dilution tunnel	65	42	144	84	240
$PM_{2.5}$, g/GJ	Dilution tunnel	65	41	143	83	220
PM_1, g/GJ	Dilution tunnel	53	34	129	72	-
Condensable PM II g/GJ	Not Applicable	14	-2	99	37	-
B[a]P mg/GJ	Dilution tunnel	41	51	101	64	150
Benzo(b)fluoranthene mg/GJ	Dilution tunnel	27	38	57	40	180
Benzo(k)fluoranthene mg/GJ	Dilution tunnel	16	22	36	25	100
Indeno(123-cd)Pyrene mg/GJ	Dilution tunnel	27	37	50	38	80
LRTAP PAH total mg/GJ	Dilution tunnel	111	148	245	168	510

Table A-3 : Charnwood C-4 blu – Modern Stove test results – ANTHRACITE

Pollutant + Method	Measurement location	Run 1	Run 2	Run 3	Average	NAEI
CO (Dry, weighted) g/GJ	Appliance outlet	4127	7085	8439	6550	2000
CO_2 (Dry, weighted) g/GJ	Appliance outlet	84814	71094	76699	77536	-
NO_x (Dry, weighted) g/GJ	Appliance outlet	78	76	60	71	150
HC (ECL Dry, weighted) g/GJ	Dilution tunnel	254	199	3535	1329	-
PM (AO) g/GJ	Appliance outlet	23	32	24	26	-
PM (DT) g/GJ	Dilution tunnel	59	585	160	268	250
Dioxins & Furans nqTEQ/GJ	Dilution tunnel	78	415	266	253	500
PAH's mg/GJ	Dilution tunnel	1113	2713	11747	5191	-
SO_2 g/GJ	Dilution tunnel	388	519	460	456	631
Condensable PM g/GJ	Dilution tunnel	36	553	137	242	250
Total PM, g/GJ	Dilution tunnel	43	64	119	75	250
PM_{10}, g/GJ	Dilution tunnel	32	18	105	52	48
$PM_{2.5}$, g/GJ	Dilution tunnel	30	14	103	49	44
PM_1, g/GJ	Dilution tunnel	25	8	90	41	-
Condensable PM II g/GJ	Not Applicable	20	32	95	49	-
B[a]P mg/GJ	Dilution tunnel	8	20	153	61	150
Benzo(b)fluoranthene mg/GJ	Dilution tunnel	7	21	146	58	180
Benzo(k)fluoranthene mg/GJ	Dilution tunnel	4	13	103	40	100
Indeno(123-cd)Pyrene mg/GJ	Dilution tunnel	6	18	186	70	80
LRTAP PAH total mg/GJ	Dilution tunnel	25	72	587	228	510

Table A-4 : Charnwood C-4 blu – Modern Stove test results – Low Sulphur MSF

Pollutant + Method	Measurement location	Run 1	Run 2	Run 3	Average	NAEI
CO (Dry, weighted) g/GJ	Appliance outlet	6467	5195	5357	5673	2000
CO_2 (Dry, weighted) g/GJ	Appliance outlet	63928	71023	69439	68130	-
NO_x (Dry, weighted) g/GJ	Appliance outlet	86	80	88	85	150
HC (ECL Dry, weighted) g/GJ	Dilution tunnel	685	1438	1702	1275	-
PM (AO) g/GJ	Appliance outlet	78	85	53	72	-
PM (DT) g/GJ	Dilution tunnel	122	180	194	165	50
Dioxins & Furans nqTEQ/GJ	Dilution tunnel	156	52	111	106	500
PAH's mg/GJ	Dilution tunnel	7196	6330	8370	7298	-
SO_2 g/GJ	Dilution tunnel	863	851	845	853	450
Condensable PM g/GJ	Dilution tunnel	45	95	142	94	50
Total PM, g/GJ	Dilution tunnel	171	401	365	312	50
PM_{10}, g/GJ	Dilution tunnel	158	350	355	288	48
$PM_{2.5}$, g/GJ	Dilution tunnel	150	297	355	268	44
PM_1, g/GJ	Dilution tunnel	142	257	270	223	-
Condensable PM II g/GJ	Not Applicable	94	316	312	241	-
B[a]P mg/GJ	Dilution tunnel	104	85	240	143	150
Benzo(b)fluoranthene mg/GJ	Dilution tunnel	98	114	100	104	180
Benzo(k)fluoranthene mg/GJ	Dilution tunnel	30	29	37	32	100
Indeno(123-cd)Pyrene mg/GJ	Dilution tunnel	27	23	88	46	80
LRTAP PAH total mg/GJ	Dilution tunnel	258	251	465	325	510

Table A-5 : Charnwood C-4 blu – Modern Stove test results – High Sulphur MSF

Pollutant + Method	Measurement location	Run 1	Run 2	Run 3	Average	NAEI
CO (Dry, weighted) g/GJ	Appliance outlet	5306	10774	6056	7378	2000
CO_2 (Dry, weighted) g/GJ	Appliance outlet	76127	131496	75437	94353	-
NO_x (Dry, weighted) g/GJ	Appliance outlet	190	280	134	201	150
HC (ECL Dry, weighted) g/GJ	Dilution tunnel	1517	2964	1026	1836	-
PM (AO) g/GJ	Appliance outlet	122	69	38	76	-
PM (DT) g/GJ	Dilution tunnel	195	582	560	446	50
Dioxins & Furans nqTEQ/GJ	Dilution tunnel	2792	4000	4058	3617	500
PAH's mg/GJ	Dilution tunnel	9003	9851	11458	10104	-
SO_2 g/GJ	Dilution tunnel	994	1384	1066	1148	450
Condensable PM g/GJ	Dilution tunnel	74	513	522	370	50
Total PM, g/GJ	Dilution tunnel	389	97	302	263	50
PM_{10}, g/GJ	Dilution tunnel	385	90	285	253	48
$PM_{2.5}$, g/GJ	Dilution tunnel	383	81	262	242	44
PM_1, g/GJ	Dilution tunnel	354	81	249	228	-
Condensable PM II g/GJ	Not Applicable	267	28	265	187	-
B[a]P mg/GJ	Dilution tunnel	198	224	250	224	150
Benzo(b)fluoranthene mg/GJ	Dilution tunnel	92	126	131	116	180
Benzo(k)fluoranthene mg/GJ	Dilution tunnel	34	44	54	44	100
Indeno(123-cd)Pyrene mg/GJ	Dilution tunnel	57	54	86	66	80
LRTAP PAH total mg/GJ	Dilution tunnel	381	447	521	450	510

Table A-6 : Charnwood C-4 blu – Modern Stove test results – COFFEE LOGS

Pollutant + Method	Measurement location	Run 1	Run 2	Run 3	Average	NAEI
CO (Dry, weighted) g/GJ	Appliance outlet	1884	2200	1884	1989	2000
CO_2 (Dry, weighted) g/GJ	Appliance outlet	73580	76577	65730	71963	-
NO_x (Dry, weighted) g/GJ	Appliance outlet	71	77	84	77	95
HC (ECL Dry, weighted) g/GJ	Dilution tunnel	165	370	305	280	-
PM (AO) g/GJ	Appliance outlet	51	81	47	60	-
PM (DT) g/GJ	Dilution tunnel	166	206	160	177	100
Dioxins & Furans nqTEQ/GJ	Dilution tunnel	33	18	4	18	100
PAH's mg/GJ	Dilution tunnel	3209	8563	9038	6937	-
SO_2 g/GJ	Dilution tunnel	117	199	159	158	11
Condensable PM g/GJ	Dilution tunnel	115	125	113	117	100
Total PM, g/GJ	Dilution tunnel	138	169	85	130	100
PM_{10}, g/GJ	Dilution tunnel	113	138	58	103	95
$PM_{2.5}$, g/GJ	Dilution tunnel	110	133	55	99	93
PM_1, g/GJ	Dilution tunnel	97	119	49	88	-
Condensable PM II g/GJ	Not Applicable	87	88	38	71	-
B[a]P mg/GJ	Dilution tunnel	19	123	118	86	10
Benzo(b)fluoranthene mg/GJ	Dilution tunnel	18	102	76	66	16
Benzo(k)fluoranthene mg/GJ	Dilution tunnel	10	62	47	40	5
Indeno(123-cd)Pyrene mg/GJ	Dilution tunnel	29	129	151	103	4
LRTAP PAH total mg/GJ	Dilution tunnel	76	416	393	295	34

Table A-7 : Dovre 500MRF Cast Iron Stove test results – COAL

Pollutant + Method	Measurement location	Run 1	Run 2	Run 3	Average	NAEI
CO (Dry, weighted) g/GJ	Appliance outlet	3028	3212	4263	3501	5000
CO_2 (Dry, weighted) g/GJ	Appliance outlet	67975	71230	71224	70143	-
NO_x (Dry, weighted) g/GJ	Appliance outlet	110	111	109	110	100
HC (ECL Dry, weighted) g/GJ	Dilution tunnel	552	440	624	539	-
PM (AO) g/GJ	Appliance outlet	38	31	66	45	-
PM (DT) g/GJ	Dilution tunnel	168	138	259	188	500
Dioxins & Furans nqTEQ/GJ	Dilution tunnel	310	566	376	417	1000
PAH's mg/GJ	Dilution tunnel	3031	4150	4691	3957	-
SO_2 g/GJ	Dilution tunnel	176	213	224	204	720
Condensable PM g/GJ	Dilution tunnel	130	107	193	143	500
Total PM, g/GJ	Dilution tunnel	138	171	213	174	500
PM_{10}, g/GJ	Dilution tunnel	127	164	206	166	450
$PM_{2.5}$, g/GJ	Dilution tunnel	121	160	205	162	450
PM_1, g/GJ	Dilution tunnel	93	133	177	134	-
Condensable PM II g/GJ	Not Applicable	100	140	146	129	-
B[a]P mg/GJ	Dilution tunnel	43	31	35	36	250
Benzo(b)fluoranthene mg/GJ	Dilution tunnel	28	29	33	30	400
Benzo(k)fluoranthene mg/GJ	Dilution tunnel	15	20	22	19	150
Indeno(123-cd)Pyrene mg/GJ	Dilution tunnel	25	30	33	29	120
LRTAP PAH total mg/GJ	Dilution tunnel	111	109	123	114	920

Table A-8 : Dovre 500MRF Cast Iron Stove test results – ANTHRACITE

Pollutant + Method	Measurement location	Run 1	Run 2	Run 3	Average	NAEI
CO (Dry, weighted) g/GJ	Appliance outlet	2768	2927	2443	2713	5000
CO_2 (Dry, weighted) g/GJ	Appliance outlet	76659	82219	77843	78907	-
NO_x (Dry, weighted) g/GJ	Appliance outlet	111	121	115	116	100
HC (ECL Dry, weighted) g/GJ	Dilution tunnel	224	65	134	141	-
PM (AO) g/GJ	Appliance outlet	28	34	27	29	-
PM (DT) g/GJ	Dilution tunnel	38	107	22	56	100
Dioxins & Furans nqTEQ/GJ	Dilution tunnel	55	15	15	29	1000
PAH's mg/GJ	Dilution tunnel	1072	1016	479	856	-
SO_2 g/GJ	Dilution tunnel	371	444	369	395	631
Condensable PM g/GJ	Dilution tunnel	11	73	-5	26	100
Total PM, g/GJ	Dilution tunnel	52	64	43	53	100
PM_{10}, g/GJ	Dilution tunnel	42	42	37	40	90
$PM_{2.5}$, g/GJ	Dilution tunnel	41	40	35	38	90
PM_1, g/GJ	Dilution tunnel	37	34	30	34	-
Condensable PM II g/GJ	Not Applicable	24	30	17	24	-
B[a]P mg/GJ	Dilution tunnel	4	2	1	2	250
Benzo(b)fluoranthene mg/GJ	Dilution tunnel	4	4	2	3	400
Benzo(k)fluoranthene mg/GJ	Dilution tunnel	2	2	1	2	150
Indeno(123-cd)Pyrene mg/GJ	Dilution tunnel	7	6	3	5	120
LRTAP PAH total mg/GJ	Dilution tunnel	17	13	6	12	920

Table A-9 : Dovre 500MRF Cast Iron Stove test results – Low Sulphur MSF

Pollutant + Method	Measurement location	Run 1	Run 2	Run 3	Average	NAEI
CO (Dry, weighted) g/GJ	Appliance outlet	3838	3678	3870	3796	5000
CO_2 (Dry, weighted) g/GJ	Appliance outlet	64840	64750	62483	64024	-
NO_x (Dry, weighted) g/GJ	Appliance outlet	97	98	98	98	100
HC (ECL Dry, weighted) g/GJ	Dilution tunnel	514	457	522	498	-
PM (AO) g/GJ	Appliance outlet	36	31	29	32	-
PM (DT) g/GJ	Dilution tunnel	120	75	109	102	100
Dioxins & Furans nqTEQ/GJ	Dilution tunnel	42	83	67	64	1000
PAH's mg/GJ	Dilution tunnel	3276	3143	2586	3002	-
SO_2 g/GJ	Dilution tunnel	717	703	693	705	900
Condensable PM g/GJ	Dilution tunnel	84	44	80	69	100
Total PM, g/GJ	Dilution tunnel	215	112	110	146	100
PM_{10}, g/GJ	Dilution tunnel	214	109	107	143	90
$PM_{2.5}$, g/GJ	Dilution tunnel	212	107	107	142	90
PM_1, g/GJ	Dilution tunnel	208	104	103	138	-
Condensable PM II g/GJ	Not Applicable	179	81	81	114	-
B[a]P mg/GJ	Dilution tunnel	79	93	69	80	250
Benzo(b)fluoranthene mg/GJ	Dilution tunnel	48	51	35	45	400
Benzo(k)fluoranthene mg/GJ	Dilution tunnel	14	16	11	13	150
Indeno(123-cd)Pyrene mg/GJ	Dilution tunnel	30	29	22	27	120
LRTAP PAH total mg/GJ	Dilution tunnel	172	189	137	166	920

Table A-10 : Dovre 500MRF Cast Iron Stove test results – High Sulphur MSF

Pollutant + Method	Measurement location	Run 1	Run 2	Run 3	Average	NAEI
CO (Dry, weighted) g/GJ	Appliance outlet	4468	4013	4774	4418	5000
CO_2 (Dry, weighted) g/GJ	Appliance outlet	72976	70755	72205	71978	-
NO_x (Dry, weighted) g/GJ	Appliance outlet	125	119	122	122	100
HC (ECL Dry, weighted) g/GJ	Dilution tunnel	825	966	1067	953	-
PM (AO) g/GJ	Appliance outlet	33	27	40	34	-
PM (DT) g/GJ	Dilution tunnel	133	126	162	140	100
Dioxins & Furans nqTEQ/GJ	Dilution tunnel	340	579	428	449	1000
PAH's mg/GJ	Dilution tunnel	3331	4323	5261	4305	-
SO_2 g/GJ	Dilution tunnel	1097	1075	1098	1090	900
Condensable PM g/GJ	Dilution tunnel	100	99	122	107	100
Total PM, g/GJ	Dilution tunnel	166	145	169	160	100
PM_{10}, g/GJ	Dilution tunnel	161	140	161	154	90
$PM_{2.5}$, g/GJ	Dilution tunnel	160	140	161	154	90
PM_1, g/GJ	Dilution tunnel	149	121	143	138	-
Condensable PM II g/GJ	Not Applicable	133	117	129	126	-
B[a]P mg/GJ	Dilution tunnel	47	36	39	41	250
Benzo(b)fluoranthene mg/GJ	Dilution tunnel	31	34	37	34	400
Benzo(k)fluoranthene mg/GJ	Dilution tunnel	17	20	25	21	150
Indeno(123-cd)Pyrene mg/GJ	Dilution tunnel	27	37	37	34	120
LRTAP PAH total mg/GJ	Dilution tunnel	122	127	138	129	920

Table A-11 : Dovre 500MRF Cast Iron Stove test results – COFFEE LOGS

Pollutant + Method	Measurement location	Run 1	Run 2	Run 3	Average	NAEI
CO (Dry, weighted) g/GJ	Appliance outlet	1258	1311	1344	1304	4000
CO_2 (Dry, weighted) g/GJ	Appliance outlet	69867	68394	75373	71212	-
NO_x (Dry, weighted) g/GJ	Appliance outlet	121	104	113	113	80
HC (ECL Dry, weighted) g/GJ	Dilution tunnel	248	181	214	214	-
PM (AO) g/GJ	Appliance outlet	59	54	77	63	-
PM (DT) g/GJ	Dilution tunnel	122	141	233	166	400
Dioxins & Furans nqTEQ/GJ	Dilution tunnel	318	71	91	160	250
PAH's mg/GJ	Dilution tunnel	2644	1290	1704	1879	-
SO_2 g/GJ	Dilution tunnel	73	89	80	81	11
Condensable PM g/GJ	Dilution tunnel	63	87	156	102	400
Total PM, g/GJ	Dilution tunnel	108	200	209	172	400
PM_{10}, g/GJ	Dilution tunnel	82	150	150	127	380
$PM_{2.5}$, g/GJ	Dilution tunnel	76	144	147	122	370
PM_1, g/GJ	Dilution tunnel	66	121	112	100	-
Condensable PM II g/GJ	Not Applicable	49	146	132	109	-
B[a]P mg/GJ	Dilution tunnel	19	8	13	13	121
Benzo(b)fluoranthene mg/GJ	Dilution tunnel	18	7	12	12	111
Benzo(k)fluoranthene mg/GJ	Dilution tunnel	10	4	7	7	42
Indeno(123-cd)Pyrene mg/GJ	Dilution tunnel	20	9	14	14	71
LRTAP PAH total mg/GJ	Dilution tunnel	67	27	45	47	345

Table A-12 : Hunter Oakwood Stove test results – COAL

Pollutant + Method	Measurement location	Run 1	Run 2	Run 3	Average	NAEI
CO (Dry, weighted) g/GJ	Appliance outlet	4587	3628	4302	4172	5000
CO_2 (Dry, weighted) g/GJ	Appliance outlet	69926	61152	72257	67778	-
NO_x (Dry, weighted) g/GJ	Appliance outlet	104	85	41	76	100
HC (ECL Dry, weighted) g/GJ	Dilution tunnel	151	240	414	268	-
PM (AO) g/GJ	Appliance outlet	86	110	110	102	-
PM (DT) g/GJ	Dilution tunnel	192	159	198	183	500
Dioxins & Furans nqTEQ/GJ	Dilution tunnel	224	187	444	285	1000
PAH's mg/GJ	Dilution tunnel	2799	3462	1456	2572	-
SO_2 g/GJ	Dilution tunnel	151	170	161	161	720
Condensable PM g/GJ	Dilution tunnel	106	49	89	81	500
Total PM, g/GJ	Dilution tunnel	204	146	186	179	500
PM_{10}, g/GJ	Dilution tunnel	106	110	145	120	450
$PM_{2.5}$, g/GJ	Dilution tunnel	95	108	141	115	450
PM_1, g/GJ	Dilution tunnel	78	100	125	101	-
Condensable PM II g/GJ	Not Applicable	118	36	77	77	-
B[a]P mg/GJ	Dilution tunnel	11	28	21	20	250
Benzo(b)fluoranthene mg/GJ	Dilution tunnel	11	25	18	18	400
Benzo(k)fluoranthene mg/GJ	Dilution tunnel	6	16	11	11	150
Indeno(123-cd)Pyrene mg/GJ	Dilution tunnel	12	21	22	18	120
LRTAP PAH total mg/GJ	Dilution tunnel	40	90	72	67	920

Table A-13 : Hunter Oakwood Stove test results – ANTHRACITE

Pollutant + Method	Measurement location	Run 1	Run 2	Run 3	Average	NAEI
CO (Dry, weighted) g/GJ	Appliance outlet	2842	3425	3065	3111	5000
CO_2 (Dry, weighted) g/GJ	Appliance outlet	80686	80287	79010	79994	-
NO_x (Dry, weighted) g/GJ	Appliance outlet	120	111	102	111	100
HC (ECL Dry, weighted) g/GJ	Dilution tunnel	158	182	172	171	-
PM (AO) g/GJ	Appliance outlet	38	34	28	33	-
PM (DT) g/GJ	Dilution tunnel	86	86	77	83	500
Dioxins & Furans nqTEQ/GJ	Dilution tunnel	85	68	36	63	1000
PAH's mg/GJ	Dilution tunnel	605	872	514	664	-
SO_2 g/GJ	Dilution tunnel	411	395	390	399	631
Condensable PM g/GJ	Dilution tunnel	48	52	49	50	500
Total PM, g/GJ	Dilution tunnel	62	55	77	65	500
PM_{10}, g/GJ	Dilution tunnel	46	37	61	48	450
$PM_{2.5}$, g/GJ	Dilution tunnel	44	35	58	45	450
PM_1, g/GJ	Dilution tunnel	39	31	53	41	-
Condensable PM II g/GJ	Not Applicable	23	22	50	32	-
B[a]P mg/GJ	Dilution tunnel	5	3	4	4	250
Benzo(b)fluoranthene mg/GJ	Dilution tunnel	6	6	6	6	400
Benzo(k)fluoranthene mg/GJ	Dilution tunnel	3	3	2	3	150
Indeno(123-cd)Pyrene mg/GJ	Dilution tunnel	5	5	4	5	120
LRTAP PAH total mg/GJ	Dilution tunnel	19	16	16	17	920

Table A-14 : Hunter Oakwood Stove test results – Low Sulphur MSF

Pollutant + Method	Measurement location	Run 1	Run 2	Run 3	Average	NAEI
CO (Dry, weighted) g/GJ	Appliance outlet	5564	4422	5127	5038	5000
CO_2 (Dry, weighted) g/GJ	Appliance outlet	62923	72721	74911	70185	-
NO_x (Dry, weighted) g/GJ	Appliance outlet	106	114	109	110	100
HC (ECL Dry, weighted) g/GJ	Dilution tunnel	258	404	536	400	-
PM (AO) g/GJ	Appliance outlet	76	91	95	87	-
PM (DT) g/GJ	Dilution tunnel	165	194	147	168	100
Dioxins & Furans nqTEQ/GJ	Dilution tunnel	227	100	70	132	1000
PAH's mg/GJ	Dilution tunnel	3237	3233	2780	3083	-
SO_2 g/GJ	Dilution tunnel	799	851	822	824	900
Condensable PM g/GJ	Dilution tunnel	89	103	52	81	100
Total PM, g/GJ	Dilution tunnel	77	121	82	93	100
PM_{10}, g/GJ	Dilution tunnel	63	103	73	80	90
$PM_{2.5}$, g/GJ	Dilution tunnel	61	102	72	78	90
PM_1, g/GJ	Dilution tunnel	55	89	59	68	-
Condensable PM II g/GJ	Not Applicable	0	31	-13	6	-
B[a]P mg/GJ	Dilution tunnel	57	106	56	73	250
Benzo(b)fluoranthene mg/GJ	Dilution tunnel	65	66	69	67	400
Benzo(k)fluoranthene mg/GJ	Dilution tunnel	18	19	18	18	150
Indeno(123-cd)Pyrene mg/GJ	Dilution tunnel	30	37	34	34	120
LRTAP PAH total mg/GJ	Dilution tunnel	170	229	177	192	920

Table A-15 : Hunter Oakwood Stove test results – High Sulphur MSF

Pollutant + Method	Measurement location	Run 1	Run 2	Run 3	Average	NAEI
CO (Dry, weighted) g/GJ	Appliance outlet	3963	4452	3602	4006	5000
CO_2 (Dry, weighted) g/GJ	Appliance outlet	74108	71698	71615	72474	-
NO_x (Dry, weighted) g/GJ	Appliance outlet	95	118	125	112	100
HC (ECL Dry, weighted) g/GJ	Dilution tunnel	686	590	570	615	-
PM (AO) g/GJ	Appliance outlet	N/A	35	31	33	-
PM (DT) g/GJ	Dilution tunnel	97	110	101	103	100
Dioxins & Furans nqTEQ/GJ	Dilution tunnel	4000	2016	1679	2565	1000
PAH's mg/GJ	Dilution tunnel	3481	4386	2975	3614	-
SO_2 g/GJ	Dilution tunnel	1080	1088	992	1054	900
Condensable PM g/GJ	Dilution tunnel	N/A	75	71	73	100
Total PM, g/GJ	Dilution tunnel	80	158	99	113	100
PM_{10}, g/GJ	Dilution tunnel	78	153	90	107	90
$PM_{2.5}$, g/GJ	Dilution tunnel	78	152	89	106	90
PM_1, g/GJ	Dilution tunnel	75	138	78	97	-
Condensable PM II g/GJ	Not Applicable	N/A	124	68	96	-
B[a]P mg/GJ	Dilution tunnel	70	95	85	83	250
Benzo(b)fluoranthene mg/GJ	Dilution tunnel	60	65	49	58	400
Benzo(k)fluoranthene mg/GJ	Dilution tunnel	17	17	16	17	150
Indeno(123-cd)Pyrene mg/GJ	Dilution tunnel	26	25	24	25	120
LRTAP PAH total mg/GJ	Dilution tunnel	172	202	174	183	920

Table A-16 : Hunter Oakwood Stove test results – COFFEE LOGS

Pollutant + Method	Measurement location	Run 1	Run 2	Run 3	Average	NAEI
CO (Dry, weighted) g/GJ	Appliance outlet	1906	1804	1785	1832	4000
CO_2 (Dry, weighted) g/GJ	Appliance outlet	75606	71029	70956	72531	-
NO_x (Dry, weighted) g/GJ	Appliance outlet	100	96	103	100	50
HC (ECL Dry, weighted) g/GJ	Dilution tunnel	262	218	191	224	-
PM (AO) g/GJ	Appliance outlet	68	60	49	59	-
PM (DT) g/GJ	Dilution tunnel	216	152	152	173	800
Dioxins & Furans nqTEQ/GJ	Dilution tunnel	51	25	23	33	800
PAH's mg/GJ	Dilution tunnel	1447	1340	942	1243	-
SO_2 g/GJ	Dilution tunnel	109	113	103	108	11
Condensable PM g/GJ	Dilution tunnel	149	92	103	115	800
Total PM, g/GJ	Dilution tunnel	164	155	140	153	800
PM_{10}, g/GJ	Dilution tunnel	119	111	103	111	760
$PM_{2.5}$, g/GJ	Dilution tunnel	117	108	98	108	740
PM_1, g/GJ	Dilution tunnel	106	99	92	99	-
Condensable PM II g/GJ	Not Applicable	97	95	91	94	-
B[a]P mg/GJ	Dilution tunnel	2	2	2	2	121
Benzo(b)fluoranthene mg/GJ	Dilution tunnel	2	3	2	2	111
Benzo(k)fluoranthene mg/GJ	Dilution tunnel	1	2	1	1	42
Indeno(123-cd)Pyrene mg/GJ	Dilution tunnel	3	4	2	3	71
LRTAP PAH total mg/GJ	Dilution tunnel	9	11	7	9	345

Table A-17 : Parkray Paragon 16 inch Fire Grate – Open Fire test results – COAL

Pollutant + Method	Measurement location	Run 1	Run 2	Run 3	Average	NAEI
CO (Dry, weighted) g/GJ	Appliance outlet	2543	1709	2593	2281	5000
CO_2 (Dry, weighted) g/GJ	Appliance outlet	49171	41323	45185	45227	-
NO_x (Dry, weighted) g/GJ	Appliance outlet	19	7	10	12	60
HC (ECL Dry, weighted) g/GJ	Dilution tunnel	729	401	686	605	-
PM (AO) g/GJ	Appliance outlet	173	129	175	159	-
PM (DT) g/GJ	Dilution tunnel	260	180	331	257	350
Dioxins & Furans nqTEQ/GJ	Dilution tunnel	29	9	11	16	500
PAH's mg/GJ	Dilution tunnel	3016	2739	5510	3755	-
SO_2 g/GJ	Dilution tunnel	164	112	179	152	720
Condensable PM g/GJ	Dilution tunnel	88	51	155	98	350
Total PM, g/GJ	Dilution tunnel	240	185	280	235	350
PM_{10}, g/GJ	Dilution tunnel	180	153	237	190	330
$PM_{2.5}$, g/GJ	Dilution tunnel	178	153	237	189	330
PM_1, g/GJ	Dilution tunnel	167	134	227	176	-
Condensable PM II g/GJ	Not Applicable	67	56	105	76	-
B[a]P mg/GJ	Dilution tunnel	29	24	62	38	100
Benzo(b)fluoranthene mg/GJ	Dilution tunnel	26	23	36	28	170
Benzo(k)fluoranthene mg/GJ	Dilution tunnel	17	16	29	21	100
Indeno(123-cd)Pyrene mg/GJ	Dilution tunnel	22	23	47	31	80
LRTAP PAH total mg/GJ	Dilution tunnel	94	86	174	118	450

Table A-18 : Parkray Paragon 16 inch Fire Grate – Open Fire test results – Low Sulphur MSF

Pollutant + Method	Measurement location	Run 1	Run 2	Run 3	Average	NAEI
CO (Dry, weighted) g/GJ	Appliance outlet	2868	2893	4253	3338	5000
CO_2 (Dry, weighted) g/GJ	Appliance outlet	45923	46748	69991	54221	-
NO_x (Dry, weighted) g/GJ	Appliance outlet	42	34	47	41	60
HC (ECL Dry, weighted) g/GJ	Dilution tunnel	722	766	819	769	-
PM (AO) g/GJ	Appliance outlet	111	123	230	155	-
PM (DT) g/GJ	Dilution tunnel	117	177	187	160	70
Dioxins & Furans nqTEQ/GJ	Dilution tunnel	30	12	15	19	500
PAH's mg/GJ	Dilution tunnel	3766	3887	3545	3732	-
SO_2 g/GJ	Dilution tunnel	515	489	792	598	500
Condensable PM g/GJ	Dilution tunnel	6	54	-44	5	70
Total PM, g/GJ	Dilution tunnel	168	206	285	220	70
PM_{10}, g/GJ	Dilution tunnel	121	184	254	186	66
$PM_{2.5}$, g/GJ	Dilution tunnel	120	182	245	182	66
PM_1, g/GJ	Dilution tunnel	117	174	234	175	-
Condensable PM II g/GJ	Not Applicable	57	83	54	65	-
B[a]P mg/GJ	Dilution tunnel	71	76	77	75	100
Benzo(b)fluoranthene mg/GJ	Dilution tunnel	43	47	69	53	170
Benzo(k)fluoranthene mg/GJ	Dilution tunnel	14	15	21	17	100
Indeno(123-cd)Pyrene mg/GJ	Dilution tunnel	31	39	42	37	80
LRTAP PAH total mg/GJ	Dilution tunnel	159	178	209	182	450

Table A-19 : Parkray Paragon 16 inch Fire Grate – Open Fire test results – High Sulphur MSF

Pollutant + Method	Measurement location	Run 1	Run 2	Run 3	Average	NAEI
CO (Dry, weighted) g/GJ	Appliance outlet	4749	3183	3454	3795	5000
CO_2 (Dry, weighted) g/GJ	Appliance outlet	85461	52409	56339	64737	-
NO_x (Dry, weighted) g/GJ	Appliance outlet	29	25	23	25	60
HC (ECL Dry, weighted) g/GJ	Dilution tunnel	1665	770	901	1112	-
PM (AO) g/GJ	Appliance outlet	249	112	154	172	-
PM (DT) g/GJ	Dilution tunnel	527	339	226	364	70
Dioxins & Furans nqTEQ/GJ	Dilution tunnel	1279	655	720	885	500
PAH's mg/GJ	Dilution tunnel	11649	6003	4573	7408	-
SO_2 g/GJ	Dilution tunnel	1088	677	767	844	500
Condensable PM g/GJ	Dilution tunnel	278	227	71	192	70
Total PM, g/GJ	Dilution tunnel	602	235	244	360	70
PM_{10}, g/GJ	Dilution tunnel	559	223	231	338	66
$PM_{2.5}$, g/GJ	Dilution tunnel	554	221	229	335	66
PM_1, g/GJ	Dilution tunnel	548	217	222	329	-
Condensable PM II g/GJ	Not Applicable	353	124	89	189	-
B[a]P mg/GJ	Dilution tunnel	257	173	115	182	100
Benzo(b)fluoranthene mg/GJ	Dilution tunnel	122	84	59	88	170
Benzo(k)fluoranthene mg/GJ	Dilution tunnel	44	27	20	30	100
Indeno(123-cd)Pyrene mg/GJ	Dilution tunnel	83	50	39	58	80
LRTAP PAH total mg/GJ	Dilution tunnel	506	334	233	358	450

Table A-20 : Parkray Paragon 16 inch Fire Grate – Open Fire test results – COFFEE LOGS

Pollutant + Method	Measurement location	Run 1	Run 2	Run 3	Average	NAEI
CO (Dry, weighted) g/GJ	Appliance outlet	2725	1660	2370	2252	4000
CO_2 (Dry, weighted) g/GJ	Appliance outlet	52145	47600	62549	54098	-
NO_x (Dry, weighted) g/GJ	Appliance outlet	9	8	3	7	50
HC (ECL Dry, weighted) g/GJ	Dilution tunnel	899	341	533	591	-
PM (AO) g/GJ	Appliance outlet	333	122	173	209	-
PM (DT) g/GJ	Dilution tunnel	760	314	458	511	880
Dioxins & Furans nqTEQ/GJ	Dilution tunnel	102	29	43	58	800
PAH's mg/GJ	Dilution tunnel	1804	887	2872	1854	-
SO_2 g/GJ	Dilution tunnel	178	108	157	148	11
Condensable PM g/GJ	Dilution tunnel	427	192	285	301	880
Total PM, g/GJ	Dilution tunnel	649	304	401	451	880
PM_{10}, g/GJ	Dilution tunnel	560	255	344	386	840
$PM_{2.5}$, g/GJ	Dilution tunnel	544	242	333	373	820
PM_1, g/GJ	Dilution tunnel	443	213	290	316	-
Condensable PM II g/GJ	Not Applicable	317	182	228	242	-
B[a]P mg/GJ	Dilution tunnel	13	7	17	12	121
Benzo(b)fluoranthene mg/GJ	Dilution tunnel	7	4	11	7	111
Benzo(k)fluoranthene mg/GJ	Dilution tunnel	3	2	6	4	42
Indeno(123-cd)Pyrene mg/GJ	Dilution tunnel	7	4	13	8	71
LRTAP PAH total mg/GJ	Dilution tunnel	30	16	47	31	345

A.4 POLLUTION MEASUREMENTS DATASET – DIOXINS AND FURANS

Table A-21 : Charnwood C-4 blu – Modern Stove test results – COAL

Pollutant + Method (ngTEQ/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
2,3,7,8 - TCDD	Dilution tunnel	54.20	25.90	137.78	72.63
1,2,3,7,8 - PeCDD	Dilution tunnel	111.22	52.56	216.33	126.70
1,2,3,4,7,8 - HxCDD	Dilution tunnel	19.60	9.72	28.84	19.39
1,2,3,6,7,8 - HxCDD	Dilution tunnel	19.45	10.36	29.10	19.64
1,2,3,7,8,9 - HxCDD	Dilution tunnel	14.18	8.32	21.92	14.80
1,2,3,4,6,7,8 - HpCDD	Dilution tunnel	8.34	5.42	12.34	8.70
OCDD	Dilution tunnel	0.69	0.50	1.01	0.74
2,3,7,8 - TCDF	Dilution tunnel	48.56	22.70	101.98	57.75
1,2,3,7,8 - PeCDF	Dilution tunnel	20.85	10.36	44.30	25.17
2,3,4,7,8 - PeCDF	Dilution tunnel	513.79	257.49	884.62	551.97
1,2,3,4,7,8 - HxCDF	Dilution tunnel	80.44	45.71	145.76	90.64
1,2,3,6,7,8 - HxCDF	Dilution tunnel	62.54	36.87	118.46	72.62
2,3,4,6,7,8 - HxCDF	Dilution tunnel	84.12	46.01	122.07	84.07
1,2,3,7,8,9 - HxCDF	Dilution tunnel	3.97	2.16	4.46	3.53
1,2,3,4,6,7,8 - HpCDF	Dilution tunnel	20.77	13.10	35.02	22.97
1,2,3,4,7,8,9 - HpCDF	Dilution tunnel	1.16	0.76	1.52	1.15
OCDF	Dilution tunnel	0.32	0.23	0.37	0.31
Total	Dilution tunnel	1064.19	548.19	1905.89	1172.76

Table A-22 : Charnwood C-4 blu – Modern Stove test results – ANTHRACITE

Pollutant + Method (ngTEQ/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
2,3,7,8 - TCDD	Dilution tunnel	14.58	56.93	28.94	33.48
1,2,3,7,8 - PeCDD	Dilution tunnel	6.20	39.87	19.87	21.98
1,2,3,4,7,8 - HxCDD	Dilution tunnel	0.29	2.56	1.08	1.31
1,2,3,6,7,8 - HxCDD	Dilution tunnel	0.70	3.67	1.77	2.05
1,2,3,7,8,9 - HxCDD	Dilution tunnel	0.34	2.90	1.26	1.50
1,2,3,4,6,7,8 - HpCDD	Dilution tunnel	0.22	0.66	0.48	0.45
OCDD	Dilution tunnel	0.05	0.07	0.06	0.06
2,3,7,8 - TCDF	Dilution tunnel	15.40	52.06	29.40	32.29
1,2,3,7,8 - PeCDF	Dilution tunnel	2.68	14.49	8.77	8.65
2,3,4,7,8 - PeCDF	Dilution tunnel	30.13	207.71	136.67	124.84
1,2,3,4,7,8 - HxCDF	Dilution tunnel	2.53	11.49	11.16	8.39
1,2,3,6,7,8 - HxCDF	Dilution tunnel	2.62	11.26	12.06	8.65
2,3,4,6,7,8 - HxCDF	Dilution tunnel	2.02	9.00	11.23	7.42
1,2,3,7,8,9 - HxCDF	Dilution tunnel	0.22	0.90	1.08	0.73
1,2,3,4,6,7,8 - HpCDF	Dilution tunnel	0.24	1.26	1.77	1.09
1,2,3,4,7,8,9 - HpCDF	Dilution tunnel	0.02	0.06	0.15	0.08
OCDF	Dilution tunnel	0.01	0.01	0.03	0.02
Total	Dilution tunnel	78.25	414.90	265.80	252.98

Table A-23 : Charnwood C-4 blu – Modern Stove test results – LOW SULPHUR MSF

Pollutant + Method (ngTEQ/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
2,3,7,8 - TCDD	Dilution tunnel	8.28	2.52	2.29	4.36
1,2,3,7,8 - PeCDD	Dilution tunnel	12.42	2.70	8.96	8.03
1,2,3,4,7,8 - HxCDD	Dilution tunnel	1.48	0.18	1.49	1.05
1,2,3,6,7,8 - HxCDD	Dilution tunnel	2.05	0.18	1.98	1.40
1,2,3,7,8,9 - HxCDD	Dilution tunnel	1.19	0.18	1.30	0.89
1,2,3,4,6,7,8 - HpCDD	Dilution tunnel	0.84	0.03	1.24	0.70
OCDD	Dilution tunnel	0.11	0.07	0.22	0.13
2,3,7,8 - TCDF	Dilution tunnel	21.46	10.26	10.44	14.06
1,2,3,7,8 - PeCDF	Dilution tunnel	5.04	1.94	2.55	3.18
2,3,4,7,8 - PeCDF	Dilution tunnel	77.23	32.22	54.32	54.59
1,2,3,4,7,8 - HxCDF	Dilution tunnel	8.46	0.32	9.38	6.05
1,2,3,6,7,8 - HxCDF	Dilution tunnel	7.45	0.32	6.29	4.69
2,3,4,6,7,8 - HxCDF	Dilution tunnel	7.09	0.32	7.93	5.12
1,2,3,7,8,9 - HxCDF	Dilution tunnel	0.32	0.36	0.69	0.46
1,2,3,4,6,7,8 - HpCDF	Dilution tunnel	2.06	0.57	2.30	1.64
1,2,3,4,7,8,9 - HpCDF	Dilution tunnel	0.11	0.02	0.08	0.07
OCDF	Dilution tunnel	0.03	3.96E-03	0.03	0.02
Total	Dilution tunnel	155.63	52.21	111.49	106.44

Table A-24 : Charnwood C-4 blu – Modern Stove test results – HIGH SULPHUR MSF

Pollutant + Method (ngTEQ/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
2,3,7,8 - TCDD	Dilution tunnel	311.40	554.63	479.08	448.37
1,2,3,7,8 - PeCDD	Dilution tunnel	142.94	197.29	189.49	176.57
1,2,3,4,7,8 - HxCDD	Dilution tunnel	7.59	7.89	6.19	7.22
1,2,3,6,7,8 - HxCDD	Dilution tunnel	7.56	8.64	7.69	7.96
1,2,3,7,8,9 - HxCDD	Dilution tunnel	6.51	6.81	4.43	5.92
1,2,3,4,6,7,8 - HpCDD	Dilution tunnel	1.74	2.10	1.42	1.75
OCDD	Dilution tunnel	0.17	0.18	0.16	0.17
2,3,7,8 - TCDF	Dilution tunnel	800.83	1161.38	1126.19	1029.47
1,2,3,7,8 - PeCDF	Dilution tunnel	107.84	151.87	171.25	143.66
2,3,4,7,8 - PeCDF	Dilution tunnel	1225.18	1689.96	1859.11	1591.42
1,2,3,4,7,8 - HxCDF	Dilution tunnel	64.77	74.82	72.93	70.84
1,2,3,6,7,8 - HxCDF	Dilution tunnel	60.30	78.17	77.22	71.90
2,3,4,6,7,8 - HxCDF	Dilution tunnel	44.99	55.46	53.27	51.24
1,2,3,7,8,9 - HxCDF	Dilution tunnel	3.29	5.43	5.04	4.59
1,2,3,4,6,7,8 - HpCDF	Dilution tunnel	5.97	5.10	3.79	4.95
1,2,3,4,7,8,9 - HpCDF	Dilution tunnel	0.39	0.54	0.42	0.45
OCDF	Dilution tunnel	0.05	0.05	0.04	0.05
Total	Dilution tunnel	2791.51	4000.32	4057.7	3616.5

Table A-25 : Charnwood C-4 blu – Modern Stove test results – COFFEE LOGS

Pollutant + Method (ngTEQ/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
2,3,7,8 - TCDD	Dilution tunnel	7.81	1.64	0.78	3.41
1,2,3,7,8 - PeCDD	Dilution tunnel	1.80	1.43	0.97	1.40
1,2,3,4,7,8 - HxCDD	Dilution tunnel	0.18	0.12	0.12	0.14
1,2,3,6,7,8 - HxCDD	Dilution tunnel	0.39	0.12	0.12	0.21
1,2,3,7,8,9 - HxCDD	Dilution tunnel	0.30	0.12	0.12	0.18
1,2,3,4,6,7,8 - HpCDD	Dilution tunnel	0.34	0.01	0.16	0.17
OCDD	Dilution tunnel	0.04	0.05	0.03	0.04
2,3,7,8 - TCDF	Dilution tunnel	5.02	4.91	1.44	3.79
1,2,3,7,8 - PeCDF	Dilution tunnel	0.75	0.57	0.04	0.45
2,3,4,7,8 - PeCDF	Dilution tunnel	12.17	8.79	0.39	7.12
1,2,3,4,7,8 - HxCDF	Dilution tunnel	0.96	0.12	0.04	0.37
1,2,3,6,7,8 - HxCDF	Dilution tunnel	1.02	0.08	0.04	0.38
2,3,4,6,7,8 - HxCDF	Dilution tunnel	1.32	0.12	0.04	0.49
1,2,3,7,8,9 - HxCDF	Dilution tunnel	0.09	0.12	0.04	0.08
1,2,3,4,6,7,8 - HpCDF	Dilution tunnel	0.29	0.13	0.09	0.17
1,2,3,4,7,8,9 - HpCDF	Dilution tunnel	0.01	0.01	0.01	0.01
OCDF	Dilution tunnel	0.01	2.05E-03	1.94E-03	0.01
Total	Dilution tunnel	32.52	18.37	4.40	18.43

Table A-26 : Dovre 500MRF Cast Iron Stove test results – COAL

Pollutant + Method (ngTEQ/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
2,3,7,8 - TCDD	Dilution tunnel	18.26	33.71	33.46	28.48
1,2,3,7,8 - PeCDD	Dilution tunnel	42.90	65.49	49.27	52.56
1,2,3,4,7,8 - HxCDD	Dilution tunnel	5.54	9.30	2.87	5.90
1,2,3,6,7,8 - HxCDD	Dilution tunnel	7.07	11.94	4.42	7.81
1,2,3,7,8,9 - HxCDD	Dilution tunnel	4.91	8.85	3.30	5.68
1,2,3,4,6,7,8 - HpCDD	Dilution tunnel	3.12	4.30	0.99	2.80
OCDD	Dilution tunnel	0.30	0.28	0.10	0.23
2,3,7,8 - TCDF	Dilution tunnel	15.95	28.73	35.28	26.65
1,2,3,7,8 - PeCDF	Dilution tunnel	9.63	17.19	14.34	13.72
2,3,4,7,8 - PeCDF	Dilution tunnel	141.23	271.48	180.94	197.88
1,2,3,4,7,8 - HxCDF	Dilution tunnel	17.73	31.90	14.73	21.45
1,2,3,6,7,8 - HxCDF	Dilution tunnel	20.01	36.20	17.32	24.51
2,3,4,6,7,8 - HxCDF	Dilution tunnel	17.95	37.10	14.98	23.34
1,2,3,7,8,9 - HxCDF	Dilution tunnel	1.68	1.95	1.27	1.63
1,2,3,4,6,7,8 - HpCDF	Dilution tunnel	3.89	6.65	2.18	4.24
1,2,3,4,7,8,9 - HpCDF	Dilution tunnel	0.22	0.43	0.10	0.25
OCDF	Dilution tunnel	0.07	0.08	0.02	0.06
Total	Dilution tunnel	310.46	565.57	375.56	417.20

Table A-27 : Dovre 500MRF Cast Iron Stove test results – ANTHRACITE

Pollutant + Method (ngTEQ/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
2,3,7,8 - TCDD	Dilution tunnel	7.02	1.47	0.87	3.12
1,2,3,7,8 - PeCDD	Dilution tunnel	4.62	0.97	0.46	2.02
1,2,3,4,7,8 - HxCDD	Dilution tunnel	0.41	0.11	0.06	0.19
1,2,3,6,7,8 - HxCDD	Dilution tunnel	0.66	0.12	0.06	0.28
1,2,3,7,8,9 - HxCDD	Dilution tunnel	0.44	0.11	0.06	0.21
1,2,3,4,6,7,8 - HpCDD	Dilution tunnel	0.32	0.01	0.06	0.13
OCDD	Dilution tunnel	0.05	0.03	0.01	0.03
2,3,7,8 - TCDF	Dilution tunnel	6.86	1.69	3.15	3.90
1,2,3,7,8 - PeCDF	Dilution tunnel	1.64	0.54	0.56	0.91
2,3,4,7,8 - PeCDF	Dilution tunnel	26.72	9.54	8.35	14.87
1,2,3,4,7,8 - HxCDF	Dilution tunnel	1.71	0.10	0.54	0.78
1,2,3,6,7,8 - HxCDF	Dilution tunnel	1.83	0.10	0.49	0.81
2,3,4,6,7,8 - HxCDF	Dilution tunnel	2.04	0.12	0.62	0.93
1,2,3,7,8,9 - HxCDF	Dilution tunnel	0.15	0.12	0.07	0.11
1,2,3,4,6,7,8 - HpCDF	Dilution tunnel	0.42	0.14	0.09	0.22
1,2,3,4,7,8,9 - HpCDF	Dilution tunnel	0.03	0.01	3.92E-03	0.01
OCDF	Dilution tunnel	0.01	1.40E-03	3.53E-03	0.01
Total	Dilution tunnel	54.94	15.19	15.47	28.53

Table A-28 : Dovre 500MRF Cast Iron Stove test results – LOW SULPHUR MSF

Pollutant + Method (ngTEQ/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
2,3,7,8 - TCDD	Dilution tunnel	4.79	6.84	1.72	4.45
1,2,3,7,8 - PeCDD	Dilution tunnel	3.70	6.55	7.76	6.00
1,2,3,4,7,8 - HxCDD	Dilution tunnel	0.10	0.14	0.19	0.14
1,2,3,6,7,8 - HxCDD	Dilution tunnel	0.10	0.14	0.17	0.14
1,2,3,7,8,9 - HxCDD	Dilution tunnel	0.10	0.14	0.17	0.14
1,2,3,4,6,7,8 - HpCDD	Dilution tunnel	0.17	0.21	0.01	0.13
OCDD	Dilution tunnel	0.02	0.03	0.02	0.02
2,3,7,8 - TCDF	Dilution tunnel	4.83	7.76	4.84	5.81
1,2,3,7,8 - PeCDF	Dilution tunnel	1.59	2.93	1.07	1.86
2,3,4,7,8 - PeCDF	Dilution tunnel	20.68	46.25	41.74	36.22
1,2,3,4,7,8 - HxCDF	Dilution tunnel	1.76	3.77	3.75	3.10
1,2,3,6,7,8 - HxCDF	Dilution tunnel	1.70	3.34	2.72	2.59
2,3,4,6,7,8 - HxCDF	Dilution tunnel	1.74	3.97	2.36	2.69
1,2,3,7,8,9 - HxCDF	Dilution tunnel	0.20	0.27	0.29	0.25
1,2,3,4,6,7,8 - HpCDF	Dilution tunnel	0.22	0.39	0.39	0.34
1,2,3,4,7,8,9 - HpCDF	Dilution tunnel	0.01	0.01	0.02	0.02
OCDF	Dilution tunnel	2.20E-03	0.01	2.68E-03	4.75E-03
Total	Dilution tunnel	41.70	82.77	67.24	63.90

Table A-29 : Dovre 500MRF Cast Iron Stove test results – HIGH SULPHUR MSF

Pollutant + Method (ngTEQ/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
2,3,7,8 - TCDD	Dilution tunnel	19.98	34.52	38.12	30.87
1,2,3,7,8 - PeCDD	Dilution tunnel	46.92	67.07	56.14	56.71
1,2,3,4,7,8 - HxCDD	Dilution tunnel	6.06	9.52	3.27	6.28
1,2,3,6,7,8 - HxCDD	Dilution tunnel	7.74	12.23	5.03	8.33
1,2,3,7,8,9 - HxCDD	Dilution tunnel	5.37	9.06	3.76	6.06
1,2,3,4,6,7,8 - HpCDD	Dilution tunnel	3.41	4.40	1.13	2.98
OCDD	Dilution tunnel	0.33	0.29	0.11	0.24
2,3,7,8 - TCDF	Dilution tunnel	17.44	29.42	40.19	29.02
1,2,3,7,8 - PeCDF	Dilution tunnel	10.53	17.61	16.34	14.83
2,3,4,7,8 - PeCDF	Dilution tunnel	154.47	278.02	206.13	212.87
1,2,3,4,7,8 - HxCDF	Dilution tunnel	19.40	32.67	16.78	22.95
1,2,3,6,7,8 - HxCDF	Dilution tunnel	21.88	37.07	19.73	26.23
2,3,4,6,7,8 - HxCDF	Dilution tunnel	19.63	38.00	17.06	24.90
1,2,3,7,8,9 - HxCDF	Dilution tunnel	1.84	1.99	1.45	1.76
1,2,3,4,6,7,8 - HpCDF	Dilution tunnel	4.25	6.81	2.48	4.52
1,2,3,4,7,8,9 - HpCDF	Dilution tunnel	0.24	0.44	0.11	0.26
OCDF	Dilution tunnel	0.08	0.08	0.03	0.06
Total	Dilution tunnel	339.57	579.20	427.85	448.87

Table A-30 : Dovre 500MRF Cast Iron Stove test results – COFFEE LOGS

Pollutant + Method (ngTEQ/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
2,3,7,8 - TCDD	Dilution tunnel	36.40	5.25	9.25	16.97
1,2,3,7,8 - PeCDD	Dilution tunnel	27.44	7.60	8.76	14.60
1,2,3,4,7,8 - HxCDD	Dilution tunnel	2.69	0.53	0.96	1.39
1,2,3,6,7,8 - HxCDD	Dilution tunnel	4.69	1.44	2.64	2.92
1,2,3,7,8,9 - HxCDD	Dilution tunnel	3.18	0.88	1.14	1.74
1,2,3,4,6,7,8 - HpCDD	Dilution tunnel	1.48	0.46	0.63	0.86
OCDD	Dilution tunnel	0.14	0.17	0.16	0.15
2,3,7,8 - TCDF	Dilution tunnel	31.56	7.49	14.97	18.01
1,2,3,7,8 - PeCDF	Dilution tunnel	10.17	2.25	2.72	5.04
2,3,4,7,8 - PeCDF	Dilution tunnel	157.10	34.06	40.73	77.30
1,2,3,4,7,8 - HxCDF	Dilution tunnel	13.53	3.28	3.31	6.71
1,2,3,6,7,8 - HxCDF	Dilution tunnel	12.82	3.27	2.81	6.30
2,3,4,6,7,8 - HxCDF	Dilution tunnel	13.51	3.72	2.54	6.59
1,2,3,7,8,9 - HxCDF	Dilution tunnel	0.67	0.21	0.16	0.34
1,2,3,4,6,7,8 - HpCDF	Dilution tunnel	2.29	0.61	0.50	1.13
1,2,3,4,7,8,9 - HpCDF	Dilution tunnel	0.15	0.07	0.04	0.09
OCDF	Dilution tunnel	0.03	0.01	0.01	0.02
Total	Dilution tunnel	317.84	71.30	91.32	160.15

Table A-31 : Hunter Oakwood Stove test results – COAL

Pollutant + Method (ngTEQ/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
2,3,7,8 - TCDD	Dilution tunnel	22.80	13.19	32.29	22.76
1,2,3,7,8 - PeCDD	Dilution tunnel	23.26	32.25	31.43	28.98
1,2,3,4,7,8 - HxCDD	Dilution tunnel	3.11	2.35	2.88	2.78
1,2,3,6,7,8 - HxCDD	Dilution tunnel	3.79	3.48	4.06	3.77
1,2,3,7,8,9 - HxCDD	Dilution tunnel	3.46	1.99	2.83	2.76
1,2,3,4,6,7,8 - HpCDD	Dilution tunnel	1.76	1.07	0.99	1.27
OCDD	Dilution tunnel	0.17	0.07	0.06	0.10
2,3,7,8 - TCDF	Dilution tunnel	20.41	21.78	33.25	25.15
1,2,3,7,8 - PeCDF	Dilution tunnel	6.20	7.21	11.92	8.45
2,3,4,7,8 - PeCDF	Dilution tunnel	102.04	77.79	157.62	112.48
1,2,3,4,7,8 - HxCDF	Dilution tunnel	9.95	6.74	14.51	10.40
1,2,3,6,7,8 - HxCDF	Dilution tunnel	10.53	8.40	14.40	11.11
2,3,4,6,7,8 - HxCDF	Dilution tunnel	12.83	8.19	135.01	52.01
1,2,3,7,8,9 - HxCDF	Dilution tunnel	0.70	0.63	0.67	0.67
1,2,3,4,6,7,8 - HpCDF	Dilution tunnel	2.63	1.32	2.31	2.08
1,2,3,4,7,8,9 - HpCDF	Dilution tunnel	0.16	0.06	0.09	0.11
OCDF	Dilution tunnel	0.04	4.82E-03	0.03	0.02
Total	Dilution tunnel	223.82	186.52	444.34	284.89

Table A-32 : Hunter Oakwood Stove test results – ANTHRACITE

Pollutant + Method (ngTEQ/GJ net)	**Measurement location**	**Run 1**	**Run 2**	**Run 3**	**Average**
2,3,7,8 - TCDD	Dilution tunnel	15.42	12.46	6.44	11.44
1,2,3,7,8 - PeCDD	Dilution tunnel	5.28	4.80	3.11	4.40
1,2,3,4,7,8 - HxCDD	Dilution tunnel	0.38	0.30	0.22	0.30
1,2,3,6,7,8 - HxCDD	Dilution tunnel	0.51	0.44	0.26	0.40
1,2,3,7,8,9 - HxCDD	Dilution tunnel	0.46	0.26	0.07	0.26
1,2,3,4,6,7,8 - HpCDD	Dilution tunnel	0.14	0.18	0.09	0.13
OCDD	Dilution tunnel	0.03	0.12	0.06	0.07
2,3,7,8 - TCDF	Dilution tunnel	18.37	15.02	7.90	13.76
1,2,3,7,8 - PeCDF	Dilution tunnel	2.62	1.77	1.15	1.85
2,3,4,7,8 - PeCDF	Dilution tunnel	35.33	27.94	14.49	25.92
1,2,3,4,7,8 - HxCDF	Dilution tunnel	2.02	1.66	0.09	1.26
1,2,3,6,7,8 - HxCDF	Dilution tunnel	2.10	1.50	0.94	1.51
2,3,4,6,7,8 - HxCDF	Dilution tunnel	1.72	1.44	0.85	1.34
1,2,3,7,8,9 - HxCDF	Dilution tunnel	0.26	0.20	0.11	0.19
1,2,3,4,6,7,8 - HpCDF	Dilution tunnel	0.25	0.30	0.13	0.22
1,2,3,4,7,8,9 - HpCDF	Dilution tunnel	0.02	0.02	0.01	0.02
OCDF	Dilution tunnel	0.01	0.01	0.01	0.01
Total	Dilution tunnel	84.93	68.42	35.94	63.09

Table A-33 : Hunter Oakwood Stove test results – Low Sulphur MSF

Pollutant + Method (ngTEQ/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
2,3,7,8 - TCDD	Dilution tunnel	25.91	7.93	8.78	14.21
1,2,3,7,8 - PeCDD	Dilution tunnel	24.34	7.63	8.78	13.58
1,2,3,4,7,8 - HxCDD	Dilution tunnel	3.27	0.76	1.04	1.69
1,2,3,6,7,8 - HxCDD	Dilution tunnel	3.98	1.49	1.30	2.26
1,2,3,7,8,9 - HxCDD	Dilution tunnel	2.91	0.88	1.14	1.64
1,2,3,4,6,7,8 - HpCDD	Dilution tunnel	1.92	0.74	0.73	1.13
OCDD	Dilution tunnel	0.34	0.39	0.20	0.31
2,3,7,8 - TCDF	Dilution tunnel	27.74	10.10	8.88	15.57
1,2,3,7,8 - PeCDF	Dilution tunnel	6.67	30.81	2.06	13.18
2,3,4,7,8 - PeCDF	Dilution tunnel	102.73	30.05	27.15	53.31
1,2,3,4,7,8 - HxCDF	Dilution tunnel	9.08	2.68	3.15	4.97
1,2,3,6,7,8 - HxCDF	Dilution tunnel	9.21	2.68	3.38	5.09
2,3,4,6,7,8 - HxCDF	Dilution tunnel	3.59	3.23	3.22	3.35
1,2,3,7,8,9 - HxCDF	Dilution tunnel	2.04	0.18	0.20	0.81
1,2,3,4,6,7,8 - HpCDF	Dilution tunnel	3.11	0.69	0.07	1.29
1,2,3,4,7,8,9 - HpCDF	Dilution tunnel	0.14	0.01	0.02	0.06
OCDF	Dilution tunnel	0.04	2.14E-03	0.01	0.02
Total	Dilution tunnel	227.04	100.27	70.11	132.47

Table A-34 : Hunter Oakwood Stove test results – High Sulphur MSF

Pollutant + Method (ngTEQ/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
2,3,7,8 - TCDD	Dilution tunnel	401.14	219.83	166.73	262.57
1,2,3,7,8 - PeCDD	Dilution tunnel	428.49	191.33	204.09	274.64
1,2,3,4,7,8 - HxCDD	Dilution tunnel	56.30	23.20	23.15	34.22
1,2,3,6,7,8 - HxCDD	Dilution tunnel	64.05	30.12	27.82	40.66
1,2,3,7,8,9 - HxCDD	Dilution tunnel	44.90	22.80	18.66	28.79
1,2,3,4,6,7,8 - HpCDD	Dilution tunnel	21.58	10.01	8.94	13.51
OCDD	Dilution tunnel	1.24	0.76	0.64	0.88
2,3,7,8 - TCDF	Dilution tunnel	601.71	331.78	245.72	393.07
1,2,3,7,8 - PeCDF	Dilution tunnel	119.66	70.73	51.38	80.59
2,3,4,7,8 - PeCDF	Dilution tunnel	1732.20	898.66	726.00	1118.95
1,2,3,4,7,8 - HxCDF	Dilution tunnel	161.60	66.97	65.39	97.98
1,2,3,6,7,8 - HxCDF	Dilution tunnel	154.53	64.73	63.16	94.14
2,3,4,6,7,8 - HxCDF	Dilution tunnel	173.68	68.39	64.98	102.35
1,2,3,7,8,9 - HxCDF	Dilution tunnel	11.15	4.50	3.05	6.23
1,2,3,4,6,7,8 - HpCDF	Dilution tunnel	25.53	11.46	8.98	15.32
1,2,3,4,7,8,9 - HpCDF	Dilution tunnel	1.52	0.93	0.68	1.04
OCDF	Dilution tunnel	0.26	0.13	0.11	0.17
Total	Dilution tunnel	3999.52	2016.35	1679.47	2565.11

Table A-35 : Hunter Oakwood Stove test results – COFFEE LOGS

Pollutant + Method (ngTEQ/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
2,3,7,8 - TCDD	Dilution tunnel	10.98	1.06	1.54	4.53
1,2,3,7,8 - PeCDD	Dilution tunnel	4.87	3.29	0.67	2.94
1,2,3,4,7,8 - HxCDD	Dilution tunnel	0.56	0.13	0.31	0.33
1,2,3,6,7,8 - HxCDD	Dilution tunnel	1.22	1.02	1.10	1.11
1,2,3,7,8,9 - HxCDD	Dilution tunnel	0.97	0.81	0.96	0.91
1,2,3,4,6,7,8 - HpCDD	Dilution tunnel	0.76	0.62	0.72	0.70
OCDD	Dilution tunnel	0.15	0.15	0.17	0.16
2,3,7,8 - TCDF	Dilution tunnel	8.20	6.20	6.55	6.98
1,2,3,7,8 - PeCDF	Dilution tunnel	1.47	0.58	0.50	0.85
2,3,4,7,8 - PeCDF	Dilution tunnel	16.99	10.08	8.47	11.85
1,2,3,4,7,8 - HxCDF	Dilution tunnel	1.53	0.32	0.60	0.82
1,2,3,6,7,8 - HxCDF	Dilution tunnel	1.53	0.49	0.50	0.84
2,3,4,6,7,8 - HxCDF	Dilution tunnel	1.37	0.57	0.60	0.85
1,2,3,7,8,9 - HxCDF	Dilution tunnel	0.15	0.06	0.06	0.09
1,2,3,4,6,7,8 - HpCDF	Dilution tunnel	0.04	0.10	0.07	0.07
1,2,3,4,7,8,9 - HpCDF	Dilution tunnel	0.01	0.00	0.01	0.01
OCDF	Dilution tunnel	0.02	0.01	5.78E-04	0.01
Total	Dilution tunnel	50.83	25.50	22.82	33.05

Table A-36 : Parkray Paragon 16 inch Fire Grate – Open Fire test results – COAL

Pollutant + Method (ngTEQ/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
2,3,7,8 - TCDD	Dilution tunnel	3.91	0.62	1.20	1.91
1,2,3,7,8 - PeCDD	Dilution tunnel	1.73	0.78	0.60	1.04
1,2,3,4,7,8 - HxCDD	Dilution tunnel	0.08	0.04	0.04	0.05
1,2,3,6,7,8 - HxCDD	Dilution tunnel	0.54	0.12	0.04	0.24
1,2,3,7,8,9 - HxCDD	Dilution tunnel	0.08	0.05	0.04	0.06
1,2,3,4,6,7,8 - HpCDD	Dilution tunnel	0.01	0.01	0.01	0.01
OCDD	Dilution tunnel	0.03	0.02	0.02	0.02
2,3,7,8 - TCDF	Dilution tunnel	5.28	2.74	1.68	3.23
1,2,3,7,8 - PeCDF	Dilution tunnel	1.06	0.36	0.37	0.60
2,3,4,7,8 - PeCDF	Dilution tunnel	13.84	3.95	5.69	7.83
1,2,3,4,7,8 - HxCDF	Dilution tunnel	1.19	0.06	0.56	0.60
1,2,3,6,7,8 - HxCDF	Dilution tunnel	0.99	0.06	0.06	0.37
2,3,4,6,7,8 - HxCDF	Dilution tunnel	0.11	0.06	0.36	0.18
1,2,3,7,8,9 - HxCDF	Dilution tunnel	0.11	0.06	0.08	0.08
1,2,3,4,6,7,8 - HpCDF	Dilution tunnel	0.16	0.04	0.09	0.10
1,2,3,4,7,8,9 - HpCDF	Dilution tunnel	0.02	0.01	0.01	0.01
OCDF	Dilution tunnel	1.66E-03	2.29E-03	2.00E-03	1.98E-03
Total	Dilution tunnel	29.15	9.01	10.84	16.33

Table A-37 : Parkray Paragon 16 inch Fire Grate – Open Fire test results – Low Sulphur MSF

Pollutant + Method (ngTEQ/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
2,3,7,8 - TCDD	Dilution tunnel	3.26	4.64	0.74	2.88
1,2,3,7,8 - PeCDD	Dilution tunnel	0.52	0.54	0.86	0.64
1,2,3,4,7,8 - HxCDD	Dilution tunnel	0.04	0.05	0.32	0.14
1,2,3,6,7,8 - HxCDD	Dilution tunnel	0.04	0.05	0.07	0.05
1,2,3,7,8,9 - HxCDD	Dilution tunnel	0.04	0.05	0.25	0.11
1,2,3,4,6,7,8 - HpCDD	Dilution tunnel	2.96E-03	3.09E-03	4.94E-03	3.66E-03
OCDD	Dilution tunnel	0.03	0.03	0.04	0.03
2,3,7,8 - TCDF	Dilution tunnel	8.22	1.28	3.04	4.18
1,2,3,7,8 - PeCDF	Dilution tunnel	1.48	0.02	0.60	0.70
2,3,4,7,8 - PeCDF	Dilution tunnel	15.26	5.10	7.90	9.42
1,2,3,4,7,8 - HxCDF	Dilution tunnel	0.01	0.02	0.62	0.22
1,2,3,6,7,8 - HxCDF	Dilution tunnel	0.01	0.02	0.02	0.02
2,3,4,6,7,8 - HxCDF	Dilution tunnel	0.81	0.03	0.05	0.30
1,2,3,7,8,9 - HxCDF	Dilution tunnel	0.03	0.03	0.05	0.04
1,2,3,4,6,7,8 - HpCDF	Dilution tunnel	0.04	0.03	0.06	0.04
1,2,3,4,7,8,9 - HpCDF	Dilution tunnel	0.01	1.55E-03	2.47E-03	4.30E-03
OCDF	Dilution tunnel	7.41E-04	7.73E-04	1.23E-03	9.16E-04
Total	Dilution tunnel	29.83	11.87	14.63	18.78

Table A-38 : Parkray Paragon 16 inch Fire Grate – Open Fire test results – High Sulphur MSF

Pollutant + Method (ngTEQ/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
2,3,7,8 - TCDD	Dilution tunnel	135.21	71.91	68.44	91.85
1,2,3,7,8 - PeCDD	Dilution tunnel	47.11	22.66	26.50	32.09
1,2,3,4,7,8 - HxCDD	Dilution tunnel	2.44	0.82	0.73	1.33
1,2,3,6,7,8 - HxCDD	Dilution tunnel	2.88	0.89	0.81	1.53
1,2,3,7,8,9 - HxCDD	Dilution tunnel	2.97	0.78	0.69	1.48
1,2,3,4,6,7,8 - HpCDD	Dilution tunnel	1.15	0.34	0.13	0.54
OCDD	Dilution tunnel	0.14	0.04	0.02	0.07
2,3,7,8 - TCDF	Dilution tunnel	380.34	185.74	190.91	252.33
1,2,3,7,8 - PeCDF	Dilution tunnel	55.83	31.86	33.41	40.37
2,3,4,7,8 - PeCDF	Dilution tunnel	584.47	313.54	364.55	420.85
1,2,3,4,7,8 - HxCDF	Dilution tunnel	19.45	9.13	11.19	13.26
1,2,3,6,7,8 - HxCDF	Dilution tunnel	22.16	9.07	12.47	14.56
2,3,4,6,7,8 - HxCDF	Dilution tunnel	21.02	7.22	8.43	12.23
1,2,3,7,8,9 - HxCDF	Dilution tunnel	1.92	0.68	1.50	1.37
1,2,3,4,6,7,8 - HpCDF	Dilution tunnel	1.63	0.53	0.40	0.85
1,2,3,4,7,8,9 - HpCDF	Dilution tunnel	0.27	0.11	0.07	0.15
OCDF	Dilution tunnel	0.04	0.01	4.26E-03	0.02
Total	Dilution tunnel	1279.05	655.34	720.26	884.88

Table A-39 : Parkray Paragon 16 inch Fire Grate – Open Fire test results – COFFEE LOGS

Pollutant + Method (ngTEQ/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
2,3,7,8 - TCDD	Dilution tunnel	3.91	0.62	1.20	1.91
1,2,3,7,8 - PeCDD	Dilution tunnel	1.73	0.78	0.60	1.04
1,2,3,4,7,8 - HxCDD	Dilution tunnel	0.08	0.04	0.04	0.05
1,2,3,6,7,8 - HxCDD	Dilution tunnel	0.54	0.12	0.04	0.24
1,2,3,7,8,9 - HxCDD	Dilution tunnel	0.08	0.05	0.04	0.06
1,2,3,4,6,7,8 - HpCDD	Dilution tunnel	0.01	0.01	0.01	0.01
OCDD	Dilution tunnel	0.03	0.02	0.02	0.02
2,3,7,8 - TCDF	Dilution tunnel	5.28	2.74	1.68	3.23
1,2,3,7,8 - PeCDF	Dilution tunnel	1.06	0.36	0.37	0.60
2,3,4,7,8 - PeCDF	Dilution tunnel	13.84	3.95	5.69	7.83
1,2,3,4,7,8 - HxCDF	Dilution tunnel	1.19	0.06	0.56	0.60
1,2,3,6,7,8 - HxCDF	Dilution tunnel	0.99	0.06	0.06	0.37
2,3,4,6,7,8 - HxCDF	Dilution tunnel	0.11	0.06	0.36	0.18
1,2,3,7,8,9 - HxCDF	Dilution tunnel	0.11	0.06	0.08	0.08
1,2,3,4,6,7,8 - HpCDF	Dilution tunnel	0.16	0.04	0.09	0.10
1,2,3,4,7,8,9 - HpCDF	Dilution tunnel	0.02	0.01	0.01	0.01
OCDF	Dilution tunnel	1.66E-03	2.29E-03	2.00E-03	1.98E-03
Total	Dilution tunnel	29.15	9.01	10.84	16.33

A.5 POLLUTANT MEASUREMENTS DATASET – PAH

Table A-40 : Charnwood C-4 blu – Modern Stove test results – COAL

Pollutant + Method (mg/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
Anthanthrene	Dilution tunnel	6.99	8.87	10.54	8.80
Benzo(a)Anthracene	Dilution tunnel	38.63	32.32	108.68	59.88
Benzo(a)pyrene	Dilution tunnel	41.33	50.79	101.27	64.46
Benzo(b)fluoranthene	Dilution tunnel	26.82	37.86	56.77	40.48
Benzo(b)naptho(2,1-d)thiophene	Dilution tunnel	0.48	0.44	1.85	0.93
Benzo(c)phenanthrene	Dilution tunnel	11.07	8.03	29.66	16.26
Benzo(ghi)Perylene	Dilution tunnel	20.37	27.86	38.61	28.95
Benzo(k)fluoranthene	Dilution tunnel	16.07	21.82	36.31	24.73
Cholanthrene	Dilution tunnel	0.23	0.51	0.40	0.38
Chrysene	Dilution tunnel	36.66	30.54	98.45	55.22
Cyclopenta(cd)pyrene	Dilution tunnel	29.03	17.76	68.53	38.44
Dibenzo (ai) pyrene	Dilution tunnel	0.83	1.33	1.37	1.18
Dibenzo(ah)Anthracene	Dilution tunnel	4.35	8.68	6.39	6.48
Fluoranthene	Dilution tunnel	139.01	104.35	378.47	207.28
Indeno(123-cd)Pyrene	Dilution tunnel	26.82	37.25	50.38	38.15
Naphthalene	Dilution tunnel	3387.91	4965.19	5983.93	4779.01
Total (Excluding Non-Detects)	Dilution tunnel	3786.60	5353.60	6971.63	5370.61
Total (Including Non-Detects)	Dilution tunnel	3786.60	5353.60	6971.63	5370.61
LRTAP PAH total	Dilution tunnel	111.04	147.72	244.73	167.83

Table A-41 : Charnwood C-4 blu – Modern Stove test results – ANTHRACITE

Pollutant + Method (mg/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
Anthanthrene	Dilution tunnel	0.96	3.97	47.98	17.64
Benzo(a)Anthracene	Dilution tunnel	9.78	41.25	234.14	95.06
Benzo(a)pyrene	Dilution tunnel	8.27	20.42	153.11	60.60
Benzo(b)fluoranthene	Dilution tunnel	6.51	20.60	145.76	57.62
Benzo(b)naptho(2,1-d)thiophene	Dilution tunnel	0.51	9.57	1.24	3.77
Benzo(c)phenanthrene	Dilution tunnel	3.83	12.55	82.41	32.93
Benzo(ghi)Perylene	Dilution tunnel	5.51	19.83	141.40	55.58
Benzo(k)fluoranthene	Dilution tunnel	4.07	12.60	102.61	39.76
Cholanthrene	Dilution tunnel	0.02	0.08	0.28	0.13
Chrysene	Dilution tunnel	9.98	45.06	236.43	97.16
Cyclopenta(cd)pyrene	Dilution tunnel	8.56	36.41	376.46	140.48
Dibenzo (ai) pyrene	Dilution tunnel	0.13	0.50	4.98	1.87
Dibenzo(ah)Anthracene	Dilution tunnel	0.61	2.09	17.28	6.66
Fluoranthene	Dilution tunnel	67.83	183.82	1154.62	468.76
Indeno(123-cd)Pyrene	Dilution tunnel	5.66	18.00	185.70	69.79
Naphthalene	Dilution tunnel	980.84	2286.34	8862.79	4043.32
Total (Excluding Non-Detects)	Dilution tunnel	1113.07	2713.10	11747.18	5191.12
Total (Including Non-Detects)	Dilution tunnel	1113.09	2713.10	11747.18	5191.12
LRTAP PAH total	Dilution tunnel	24.52	71.62	587.18	227.77

Table A-42 : Charnwood C-4 blu – Modern Stove test results – Low Sulphur MSF

Pollutant + Method (mg/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
Anthanthrene	Dilution tunnel	9.02	69.79	28.40	35.74
Benzo(a)Anthracene	Dilution tunnel	220.06	247.70	283.99	250.58
Benzo(a)pyrene	Dilution tunnel	103.90	84.98	240.42	143.10
Benzo(b)fluoranthene	Dilution tunnel	97.76	113.91	100.14	103.94
Benzo(b)naptho(2,1-d)thiophene	Dilution tunnel	169.55	189.84	243.86	201.08
Benzo(c)phenanthrene	Dilution tunnel	33.95	35.00	40.52	36.49
Benzo(ghi)Perylene	Dilution tunnel	62.41	54.60	277.49	131.50
Benzo(k)fluoranthene	Dilution tunnel	29.91	29.43	36.77	32.04
Cholanthrene	Dilution tunnel	0.55	0.39	0.77	0.57
Chrysene	Dilution tunnel	260.46	296.52	307.69	288.22
Cyclopenta(cd)pyrene	Dilution tunnel	93.07	28.64	96.70	72.80
Dibenzo (ai) pyrene	Dilution tunnel	0.97	0.99	7.80	3.25
Dibenzo(ah)Anthracene	Dilution tunnel	19.48	19.17	38.60	25.75
Fluoranthene	Dilution tunnel	288.60	250.59	345.14	294.78
Indeno(123-cd)Pyrene	Dilution tunnel	26.77	22.78	87.53	45.69
Naphthalene	Dilution tunnel	5779.25	4885.31	6234.00	5632.85
Total (Excluding Non-Detects)	Dilution tunnel	7186.69	6259.86	8369.81	7272.12
Total (Including Non-Detects)	Dilution tunnel	7195.70	6329.65	8369.81	7298.39
LRTAP PAH total	Dilution tunnel	258.33	251.10	464.86	324.76

Table A-43 : Charnwood C-4 blu – Modern Stove test results – High Sulphur MSF

Pollutant + Method (mg/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
Anthanthrene	Dilution tunnel	19.62	16.78	28.40	21.60
Benzo(a)Anthracene	Dilution tunnel	281.60	360.87	410.28	350.92
Benzo(a)pyrene	Dilution tunnel	197.79	224.11	250.45	224.11
Benzo(b)fluoranthene	Dilution tunnel	92.07	125.65	131.29	116.34
Benzo(b)naptho(2,1-d)thiophene	Dilution tunnel	232.71	297.66	272.57	267.65
Benzo(c)phenanthrene	Dilution tunnel	37.78	40.99	54.94	44.57
Benzo(ghi)Perylene	Dilution tunnel	158.10	169.32	204.78	177.40
Benzo(k)fluoranthene	Dilution tunnel	33.97	44.05	53.52	43.85
Cholanthrene	Dilution tunnel	0.39	0.42	0.64	0.48
Chrysene	Dilution tunnel	352.39	463.53	460.23	425.39
Cyclopenta(cd)pyrene	Dilution tunnel	74.29	52.87	132.72	86.62
Dibenzo (ai) pyrene	Dilution tunnel	4.86	3.95	6.17	4.99
Dibenzo(ah)Anthracene	Dilution tunnel	60.00	70.10	75.99	68.70
Fluoranthene	Dilution tunnel	349.22	368.91	581.53	433.22
Indeno(123-cd)Pyrene	Dilution tunnel	57.15	53.63	85.98	65.59
Naphthalene	Dilution tunnel	7051.06	7558.30	8708.70	7772.69
Total (Excluding Non-Detects)	Dilution tunnel	9002.99	9851.15	11458.20	10104.12
Total (Including Non-Detects)	Dilution tunnel	9002.99	9851.15	11458.20	10104.12
LRTAP PAH total	Dilution tunnel	380.97	447.45	521.24	449.88

Table A-44 : Charnwood C-4 blu – Modern Stove test results – COFFEE LOGS

Pollutant + Method (mg/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
Anthanthrene	Dilution tunnel	0.74	7.05	8.47	5.42
Benzo(a)Anthracene	Dilution tunnel	18.51	107.75	78.21	68.16
Benzo(a)pyrene	Dilution tunnel	18.72	122.50	117.51	86.24
Benzo(b)fluoranthene	Dilution tunnel	17.82	102.43	76.30	65.52
Benzo(b)naptho(2,1-d)thiophene	Dilution tunnel	0.51	1.23	0.55	0.76
Benzo(c)phenanthrene	Dilution tunnel	5.83	35.15	23.96	21.65
Benzo(ghi)Perylene	Dilution tunnel	28.10	129.06	156.04	104.40
Benzo(k)fluoranthene	Dilution tunnel	10.40	62.28	47.31	40.00
Cholanthrene	Dilution tunnel	0.03	0.04	0.04	0.04
Chrysene	Dilution tunnel	21.20	127.01	83.17	77.13
Cyclopenta(cd)pyrene	Dilution tunnel	7.38	152.82	88.51	82.91
Dibenzo (ai) pyrene	Dilution tunnel	0.50	2.29	3.70	2.16
Dibenzo(ah)Anthracene	Dilution tunnel	2.37	9.22	11.75	7.78
Fluoranthene	Dilution tunnel	129.46	696.50	526.49	450.81
Indeno(123-cd)Pyrene	Dilution tunnel	29.24	128.65	151.46	103.12
Naphthalene	Dilution tunnel	2918.06	6878.94	7664.56	5820.52
Total (Excluding Non-Detects)	Dilution tunnel	3208.84	8562.86	9037.97	6936.56
Total (Including Non-Detects)	Dilution tunnel	3208.87	8562.90	9038.00	6936.59
LRTAP PAH total	Dilution tunnel	76.18	415.85	392.57	294.87

Table A-45 : Dovre 500MRF Cast Iron Stove test results – COAL

Pollutant + Method (mg/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
Anthanthrene	Dilution tunnel	6.70	9.96	11.25	9.30
Benzo(a)Anthracene	Dilution tunnel	28.67	50.50	57.08	45.42
Benzo(a)pyrene	Dilution tunnel	42.69	30.75	34.75	36.07
Benzo(b)fluoranthene	Dilution tunnel	27.84	28.92	32.68	29.81
Benzo(b)naptho(2,1-d)thiophene	Dilution tunnel	2.11	1.94	2.19	2.08
Benzo(c)phenanthrene	Dilution tunnel	5.34	13.64	15.42	11.47
Benzo(ghi)Perylene	Dilution tunnel	18.98	22.81	25.78	22.52
Benzo(k)fluoranthene	Dilution tunnel	15.47	19.81	22.39	19.22
Cholanthrene	Dilution tunnel	0.26	0.47	0.53	0.42
Chrysene	Dilution tunnel	27.21	42.36	47.87	39.14
Cyclopenta(cd)pyrene	Dilution tunnel	16.24	32.79	37.05	28.69
Dibenzo (ai) pyrene	Dilution tunnel	1.16	1.03	1.16	1.12
Dibenzo(ah)Anthracene	Dilution tunnel	4.02	4.62	5.22	4.62
Fluoranthene	Dilution tunnel	59.65	165.15	186.65	137.15
Indeno(123-cd)Pyrene	Dilution tunnel	24.91	29.53	33.37	29.27
Naphthalene	Dilution tunnel	2750.02	3696.04	4177.18	3541.08
Total (Excluding Non-Detects)	Dilution tunnel	3031.26	4150.31	4690.59	3957.39
Total (Including Non-Detects)	Dilution tunnel	3031.26	4150.31	4690.59	3957.39
LRTAP PAH total	Dilution tunnel	110.90	109.01	123.20	114.37

Table A-46 : Dovre 500MRF Cast Iron Stove test results – ANTHRACITE

Pollutant + Method (mg/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
Anthanthrene	Dilution tunnel	1.15	0.22	0.10	0.49
Benzo(a)Anthracene	Dilution tunnel	4.62	5.15	2.43	4.07
Benzo(a)pyrene	Dilution tunnel	3.88	1.75	0.82	2.15
Benzo(b)fluoranthene	Dilution tunnel	3.91	3.77	1.78	3.15
Benzo(b)naptho(2,1-d)thiophene	Dilution tunnel	0.21	0.35	0.17	0.24
Benzo(c)phenanthrene	Dilution tunnel	1.55	1.70	0.80	1.35
Benzo(ghi)Perylene	Dilution tunnel	7.65	5.86	2.77	5.43
Benzo(k)fluoranthene	Dilution tunnel	2.37	1.51	0.71	1.53
Cholanthrene	Dilution tunnel	0.01	0.08	0.04	0.04
Chrysene	Dilution tunnel	4.77	3.61	1.70	3.36
Cyclopenta(cd)pyrene	Dilution tunnel	2.15	0.48	0.23	0.95
Dibenzo (ai) pyrene	Dilution tunnel	0.17	0.11	0.05	0.11
Dibenzo(ah)Anthracene	Dilution tunnel	0.79	1.16	0.55	0.83
Fluoranthene	Dilution tunnel	35.21	36.28	17.12	29.54
Indeno(123-cd)Pyrene	Dilution tunnel	6.97	5.67	2.68	5.11
Naphthalene	Dilution tunnel	996.89	948.17	447.37	797.48
Total (Excluding Non-Detects)	Dilution tunnel	1072.28	1015.79	479.28	855.79
Total (Including Non-Detects)	Dilution tunnel	1072.30	1015.87	479.32	855.83
LRTAP PAH total	Dilution tunnel	17.12	12.71	5.99	11.94

Table A-47 : Dovre 500MRF Cast Iron Stove test results – Low Sulphur MSF

Pollutant + Method (mg/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
Anthanthrene	Dilution tunnel	8.13	6.99	5.71	6.94
Benzo(a)Anthracene	Dilution tunnel	71.71	104.61	42.10	72.80
Benzo(a)pyrene	Dilution tunnel	79.12	93.29	68.77	80.39
Benzo(b)fluoranthene	Dilution tunnel	48.07	50.94	35.43	44.81
Benzo(b)naptho(2,1-d)thiophene	Dilution tunnel	60.29	84.90	33.53	59.57
Benzo(c)phenanthrene	Dilution tunnel	8.79	13.19	5.94	9.31
Benzo(ghi)Perylene	Dilution tunnel	87.94	120.61	74.10	94.21
Benzo(k)fluoranthene	Dilution tunnel	14.10	15.52	10.74	13.45
Cholanthrene	Dilution tunnel	0.24	0.21	0.16	0.20
Chrysene	Dilution tunnel	86.33	122.17	51.43	86.65
Cyclopenta(cd)pyrene	Dilution tunnel	13.58	25.57	12.80	17.32
Dibenzo (ai) pyrene	Dilution tunnel	2.54	2.85	1.80	2.40
Dibenzo(ah)Anthracene	Dilution tunnel	26.84	28.30	22.48	25.87
Fluoranthene	Dilution tunnel	97.95	124.51	62.48	94.98
Indeno(123-cd)Pyrene	Dilution tunnel	30.25	29.27	21.72	27.08
Naphthalene	Dilution tunnel	2640.07	2320.48	2137.25	2365.93
Total (Excluding Non-Detects)	Dilution tunnel	3275.96	3143.40	2586.44	3001.93
Total (Including Non-Detects)	Dilution tunnel	3275.96	3143.40	2586.44	3001.93
LRTAP PAH total	Dilution tunnel	171.54	189.01	136.65	165.74

Table A-48 : Dovre 500MRF Cast Iron Stove test results – High Sulphur MSF

Pollutant + Method (mg/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
Anthanthrene	Dilution tunnel	7.36	10.44	12.62	10.14
Benzo(a)Anthracene	Dilution tunnel	31.51	29.89	64.01	41.80
Benzo(a)pyrene	Dilution tunnel	46.91	36.20	38.98	40.70
Benzo(b)fluoranthene	Dilution tunnel	30.59	33.63	36.65	33.62
Benzo(b)naptho(2,1-d)thiophene	Dilution tunnel	2.32	1.82	2.46	2.20
Benzo(c)phenanthrene	Dilution tunnel	5.86	5.77	17.29	9.64
Benzo(ghi)Perylene	Dilution tunnel	20.86	26.86	28.91	25.54
Benzo(k)fluoranthene	Dilution tunnel	17.00	20.39	25.11	20.83
Cholanthrene	Dilution tunnel	0.28	0.37	0.59	0.41
Chrysene	Dilution tunnel	29.90	26.62	53.69	36.74
Cyclopenta(cd)pyrene	Dilution tunnel	17.85	16.53	41.56	25.31
Dibenzo (ai) pyrene	Dilution tunnel	1.28	1.13	1.31	1.24
Dibenzo(ah)Anthracene	Dilution tunnel	4.42	5.79	5.86	5.36
Fluoranthene	Dilution tunnel	65.54	60.96	209.33	111.94
Indeno(123-cd)Pyrene	Dilution tunnel	27.37	36.90	37.43	33.90
Naphthalene	Dilution tunnel	3021.86	4009.96	4684.78	3905.53
Total (Excluding Non-Detects)	Dilution tunnel	3330.89	4323.26	5260.58	4304.91
Total (Including Non-Detects)	Dilution tunnel	3330.89	4323.26	5260.58	4304.91
LRTAP PAH total	Dilution tunnel	121.86	127.12	138.17	129.05

Table A-49 : Dovre 500MRF Cast Iron Stove test results – COFFEE LOGS

Pollutant + Method (mg/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
Anthanthrene	Dilution tunnel	0.86	0.82	1.21	0.96
Benzo(a)Anthracene	Dilution tunnel	24.80	10.94	17.31	17.68
Benzo(a)pyrene	Dilution tunnel	18.64	7.66	13.29	13.20
Benzo(b)fluoranthene	Dilution tunnel	17.78	6.74	11.50	12.01
Benzo(b)naptho(2,1-d)thiophene	Dilution tunnel	1.40	0.60	0.54	0.85
Benzo(c)phenanthrene	Dilution tunnel	8.03	3.94	5.73	5.90
Benzo(ghi)Perylene	Dilution tunnel	18.21	7.31	12.48	12.66
Benzo(k)fluoranthene	Dilution tunnel	10.48	4.26	6.89	7.21
Cholanthrene	Dilution tunnel	0.04	0.02	0.02	0.03
Chrysene	Dilution tunnel	25.09	12.71	19.82	19.21
Cyclopenta(cd)pyrene	Dilution tunnel	33.11	5.69	21.39	20.06
Dibenzo (ai) pyrene	Dilution tunnel	0.34	0.17	0.23	0.25
Dibenzo(ah)Anthracene	Dilution tunnel	2.01	0.72	1.20	1.31
Fluoranthene	Dilution tunnel	161.98	63.64	96.96	107.53
Indeno(123-cd)Pyrene	Dilution tunnel	20.21	8.72	13.52	14.15
Naphthalene	Dilution tunnel	2300.75	1156.09	1481.81	1646.22
Total (Excluding Non-Detects)	Dilution tunnel	2643.71	1290.00	1703.89	1879.20
Total (Including Non-Detects)	Dilution tunnel	2643.71	1290.02	1703.91	1879.21
LRTAP PAH total	Dilution tunnel	67.10	27.38	45.20	46.56

Table A-50 : Hunter Oakwood Stove test results – COAL

Pollutant + Method (mg/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
Anthanthrene	Dilution tunnel	1.72	6.41	6.26	4.80
Benzo(a)Anthracene	Dilution tunnel	13.04	25.40	15.98	18.14
Benzo(a)pyrene	Dilution tunnel	10.80	27.69	20.73	19.74
Benzo(b)fluoranthene	Dilution tunnel	11.35	25.40	18.43	18.39
Benzo(b)naptho(2,1-d)thiophene	Dilution tunnel	0.71	1.01	0.97	0.89
Benzo(c)phenanthrene	Dilution tunnel	3.10	7.64	3.56	4.77
Benzo(ghi)Perylene	Dilution tunnel	10.45	15.15	14.91	13.51
Benzo(k)fluoranthene	Dilution tunnel	6.12	16.07	10.73	10.97
Cholanthrene	Dilution tunnel	0.09	0.27	0.17	0.18
Chrysene	Dilution tunnel	11.02	21.65	14.76	15.81
Cyclopenta(cd)pyrene	Dilution tunnel	8.83	22.27	9.28	13.46
Dibenzo (ai) pyrene	Dilution tunnel	0.42	0.73	0.92	0.69
Dibenzo(ah)Anthracene	Dilution tunnel	3.29	4.27	3.60	3.72
Fluoranthene	Dilution tunnel	45.00	92.22	37.28	58.17
Indeno(123-cd)Pyrene	Dilution tunnel	12.03	21.23	21.69	18.32
Naphthalene	Dilution tunnel	2661.25	3174.50	1276.40	2370.72
Total (Excluding Non-Detects)	Dilution tunnel	2799.22	3461.90	1455.68	2572.27
Total (Including Non-Detects)	Dilution tunnel	2799.22	3461.90	1455.68	2572.27
LRTAP PAH total	Dilution tunnel	40.30	90.38	71.58	67.42

Table A-51 : Hunter Oakwood Stove test results – ANTHRACITE

Pollutant + Method (mg/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
Anthanthrene	Dilution tunnel	0.16	0.11	0.26	0.17
Benzo(a)Anthracene	Dilution tunnel	6.16	5.44	5.10	5.57
Benzo(a)pyrene	Dilution tunnel	4.54	3.22	3.71	3.82
Benzo(b)fluoranthene	Dilution tunnel	6.33	5.51	5.60	5.81
Benzo(b)naptho(2,1-d)thiophene	Dilution tunnel	0.88	0.40	1.19	0.82
Benzo(c)phenanthrene	Dilution tunnel	2.35	2.33	1.76	2.15
Benzo(ghi)Perylene	Dilution tunnel	5.21	4.89	4.60	4.90
Benzo(k)fluoranthene	Dilution tunnel	2.93	2.64	2.21	2.59
Cholanthrene	Dilution tunnel	0.03	0.02	0.02	0.02
Chrysene	Dilution tunnel	7.62	6.98	6.28	6.96
Cyclopenta(cd)pyrene	Dilution tunnel	1.46	2.07	1.69	1.74
Dibenzo (ai) pyrene	Dilution tunnel	0.07	0.07	0.11	0.08
Dibenzo(ah)Anthracene	Dilution tunnel	0.59	0.47	0.51	0.53
Fluoranthene	Dilution tunnel	40.05	47.57	27.99	38.53
Indeno(123-cd)Pyrene	Dilution tunnel	5.31	4.60	4.19	4.70
Naphthalene	Dilution tunnel	521.41	786.16	448.59	585.39
Total (Excluding Non-Detects)	Dilution tunnel	605.06	872.48	513.78	663.77
Total (Including Non-Detects)	Dilution tunnel	605.09	872.48	513.80	663.79
LRTAP PAH total	Dilution tunnel	19.11	15.97	15.70	16.92

Table A-52 : Hunter Oakwood Stove test results – Low Sulphur MSF

Pollutant + Method (mg/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
Anthanthrene	Dilution tunnel	2.50	8.22	5.99	5.57
Benzo(a)Anthracene	Dilution tunnel	125.60	147.42	116.61	129.88
Benzo(a)pyrene	Dilution tunnel	57.14	106.30	56.04	73.16
Benzo(b)fluoranthene	Dilution tunnel	64.60	66.40	68.67	66.56
Benzo(b)naptho(2,1-d)thiophene	Dilution tunnel	129.46	131.28	137.67	132.80
Benzo(c)phenanthrene	Dilution tunnel	18.69	18.92	16.59	18.06
Benzo(ghi)Perylene	Dilution tunnel	67.17	84.07	97.18	82.81
Benzo(k)fluoranthene	Dilution tunnel	18.14	18.55	18.30	18.33
Cholanthrene	Dilution tunnel	0.54	0.21	0.12	0.29
Chrysene	Dilution tunnel	164.46	175.14	197.92	179.17
Cyclopenta(cd)pyrene	Dilution tunnel	1.89	37.46	3.56	14.31
Dibenzo (ai) pyrene	Dilution tunnel	0.86	2.58	2.28	1.91
Dibenzo(ah)Anthracene	Dilution tunnel	29.60	38.68	31.91	33.40
Fluoranthene	Dilution tunnel	171.15	173.31	144.15	162.87
Indeno(123-cd)Pyrene	Dilution tunnel	30.11	37.46	33.69	33.76
Naphthalene	Dilution tunnel	2354.95	2186.97	1849.62	2130.51
Total (Excluding Non-Detects)	Dilution tunnel	3236.85	3233.00	2780.29	3083.38
Total (Including Non-Detects)	Dilution tunnel	3236.85	3233.00	2780.29	3083.38
LRTAP PAH total	Dilution tunnel	169.99	228.72	176.70	191.80

Table A-53 : Hunter Oakwood Stove test results – High Sulphur MSF

Pollutant + Method (mg/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
Anthanthrene	Dilution tunnel	7.10	6.84	5.61	6.51
Benzo(a)Anthracene	Dilution tunnel	149.36	155.34	125.02	143.24
Benzo(a)pyrene	Dilution tunnel	69.82	94.51	84.73	83.02
Benzo(b)fluoranthene	Dilution tunnel	59.88	65.12	49.22	58.07
Benzo(b)naptho(2,1-d)thiophene	Dilution tunnel	144.84	137.79	101.76	128.13
Benzo(c)phenanthrene	Dilution tunnel	19.39	19.56	15.24	18.06
Benzo(ghi)Perylene	Dilution tunnel	67.11	54.10	46.73	55.98
Benzo(k)fluoranthene	Dilution tunnel	16.77	17.05	16.41	16.74
Cholanthrene	Dilution tunnel	0.10	0.23	0.17	0.17
Chrysene	Dilution tunnel	184.84	192.50	150.78	176.04
Cyclopenta(cd)pyrene	Dilution tunnel	2.26	20.37	16.91	13.18
Dibenzo (ai) pyrene	Dilution tunnel	1.44	1.28	1.19	1.30
Dibenzo(ah)Anthracene	Dilution tunnel	33.67	26.74	24.09	28.17
Fluoranthene	Dilution tunnel	170.15	179.02	153.48	167.55
Indeno(123-cd)Pyrene	Dilution tunnel	25.99	24.90	24.09	24.99
Naphthalene	Dilution tunnel	2528.52	3390.64	2159.89	2693.02
Total (Excluding Non-Detects)	Dilution tunnel	3481.23	4385.98	2975.33	3614.18
Total (Including Non-Detects)	Dilution tunnel	3481.23	4385.98	2975.33	3614.18
LRTAP PAH total	Dilution tunnel	172.45	201.58	174.45	182.83

Table A-54 : Hunter Oakwood Stove test results – COFFEE LOGS

Pollutant + Method (mg/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
Anthanthrene	Dilution tunnel	0.26	0.14	0.15	0.18
Benzo(a)Anthracene	Dilution tunnel	3.93	5.13	3.61	4.22
Benzo(a)pyrene	Dilution tunnel	2.12	2.40	2.29	2.27
Benzo(b)fluoranthene	Dilution tunnel	2.44	2.62	1.81	2.29
Benzo(b)naptho(2,1-d)thiophene	Dilution tunnel	0.73	0.26	0.19	0.39
Benzo(c)phenanthrene	Dilution tunnel	1.24	1.69	1.22	1.38
Benzo(ghi)Perylene	Dilution tunnel	3.08	3.28	2.16	2.84
Benzo(k)fluoranthene	Dilution tunnel	1.16	1.54	1.03	1.25
Cholanthrene	Dilution tunnel	0.03	0.03	0.03	0.03
Chrysene	Dilution tunnel	5.87	6.76	4.96	5.86
Cyclopenta(cd)pyrene	Dilution tunnel	1.18	2.47	1.94	1.86
Dibenzo (ai) pyrene	Dilution tunnel	0.04	0.06	0.05	0.05
Dibenzo(ah)Anthracene	Dilution tunnel	0.36	0.36	0.24	0.32
Fluoranthene	Dilution tunnel	24.35	31.10	21.95	25.80
Indeno(123-cd)Pyrene	Dilution tunnel	3.16	3.95	2.27	3.13
Naphthalene	Dilution tunnel	1396.64	1278.25	897.75	1190.88
Total (Excluding Non-Detects)	Dilution tunnel	1446.58	1340.00	941.63	1242.74
Total (Including Non-Detects)	Dilution tunnel	1446.60	1340.02	941.66	1242.76
LRTAP PAH total	Dilution tunnel	8.88	10.51	7.41	8.93

Table A-55 : Parkray Paragon 16 inch Fire Grate – Open Fire test results – COAL

Pollutant + Method (mg/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
Anthanthrene	Dilution tunnel	6.70	5.13	18.13	9.99
Benzo(a)Anthracene	Dilution tunnel	60.75	65.12	104.46	76.78
Benzo(a)pyrene	Dilution tunnel	29.24	24.17	61.64	38.35
Benzo(b)fluoranthene	Dilution tunnel	25.60	22.78	35.82	28.07
Benzo(b)naptho(2,1-d)thiophene	Dilution tunnel	6.38	5.85	2.60	4.94
Benzo(c)phenanthrene	Dilution tunnel	16.06	18.07	29.82	21.32
Benzo(ghi)Perylene	Dilution tunnel	15.45	16.04	31.22	20.90
Benzo(k)fluoranthene	Dilution tunnel	16.82	15.61	29.42	20.62
Cholanthrene	Dilution tunnel	0.55	0.26	0.73	0.52
Chrysene	Dilution tunnel	51.51	56.56	80.85	62.98
Cyclopenta(cd)pyrene	Dilution tunnel	33.03	21.39	104.06	52.83
Dibenzo (ai) pyrene	Dilution tunnel	0.84	0.56	1.89	1.10
Dibenzo(ah)Anthracene	Dilution tunnel	2.11	1.57	2.80	2.16
Fluoranthene	Dilution tunnel	151.51	202.09	290.18	214.59
Indeno(123-cd)Pyrene	Dilution tunnel	22.27	23.31	47.03	30.87
Naphthalene	Dilution tunnel	2577.13	2260.42	4668.90	3168.82
Total (Excluding Non-Detects)	Dilution tunnel	3015.94	2738.93	5509.56	3754.81
Total (Including Non-Detects)	Dilution tunnel	3015.94	2738.93	5509.56	3754.81
LRTAP PAH total	Dilution tunnel	93.93	85.86	173.91	117.90

Table A-56 : Parkray Paragon 16 inch Fire Grate – Open Fire test results – Low Sulphur MSF

Pollutant + Method (mg/GJ net)	**Measurement location**	**Run 1**	**Run 2**	**Run 3**	**Average**
Anthanthrene	Dilution tunnel	11.32	14.51	14.13	13.32
Benzo(a)Anthracene	Dilution tunnel	84.84	64.58	110.32	86.58
Benzo(a)pyrene	Dilution tunnel	71.23	76.19	77.02	74.82
Benzo(b)fluoranthene	Dilution tunnel	43.44	47.39	68.89	53.24
Benzo(b)naptho(2,1-d)thiophene	Dilution tunnel	77.52	54.36	146.67	92.85
Benzo(c)phenanthrene	Dilution tunnel	15.36	8.55	19.32	14.41
Benzo(ghi)Perylene	Dilution tunnel	61.43	61.79	86.68	69.97
Benzo(k)fluoranthene	Dilution tunnel	13.88	15.18	20.97	16.68
Cholanthrene	Dilution tunnel	0.25	0.29	0.22	0.25
Chrysene	Dilution tunnel	91.13	80.22	192.93	121.43
Cyclopenta(cd)pyrene	Dilution tunnel	44.17	8.10	12.02	21.43
Dibenzo (ai) pyrene	Dilution tunnel	2.16	3.21	4.35	3.24
Dibenzo(ah)Anthracene	Dilution tunnel	28.08	30.97	35.08	31.38
Fluoranthene	Dilution tunnel	152.12	71.24	179.46	134.27
Indeno(123-cd)Pyrene	Dilution tunnel	30.57	39.49	42.20	37.42
Naphthalene	Dilution tunnel	3038.05	3310.95	2534.30	2961.10
Total (Excluding Non-Detects)	Dilution tunnel	3765.57	3886.99	3544.55	3732.37
Total (Including Non-Detects)	Dilution tunnel	3765.57	3886.99	3544.55	3732.37
LRTAP PAH total	Dilution tunnel	159.13	178.25	209.07	182.15

Table A-57 : Parkray Paragon 16 inch Fire Grate – Open Fire test results – High Sulphur MSF

Pollutant + Method (mg/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
Anthanthrene	Dilution tunnel	35.18	16.03	9.84	20.35
Benzo(a)Anthracene	Dilution tunnel	236.87	157.95	124.08	172.97
Benzo(a)pyrene	Dilution tunnel	257.05	172.68	115.33	181.69
Benzo(b)fluoranthene	Dilution tunnel	121.95	83.94	58.99	88.29
Benzo(b)naptho(2,1-d)thiophene	Dilution tunnel	219.33	139.10	99.06	152.50
Benzo(c)phenanthrene	Dilution tunnel	37.90	22.51	16.90	25.77
Benzo(ghi)Perylene	Dilution tunnel	168.44	82.23	61.02	103.90
Benzo(k)fluoranthene	Dilution tunnel	44.13	27.27	19.55	30.32
Cholanthrene	Dilution tunnel	1.06	0.52	0.21	0.60
Chrysene	Dilution tunnel	263.19	191.87	149.91	201.66
Cyclopenta(cd)pyrene	Dilution tunnel	125.45	67.50	27.05	73.33
Dibenzo (ai) pyrene	Dilution tunnel	10.35	4.73	2.97	6.02
Dibenzo(ah)Anthracene	Dilution tunnel	61.85	37.35	43.53	47.57
Fluoranthene	Dilution tunnel	323.73	206.60	172.89	234.41
Indeno(123-cd)Pyrene	Dilution tunnel	83.34	50.37	38.85	57.52
Naphthalene	Dilution tunnel	9659.13	4741.87	3632.77	6011.26
Total (Excluding Non-Detects)	Dilution tunnel	11613.78	5986.48	4563.10	7387.78
Total (Including Non-Detects)	Dilution tunnel	11648.96	6002.51	4572.94	7408.14
LRTAP PAH total	Dilution tunnel	506.47	334.26	232.71	357.81

Table A-58 : Parkray Paragon 16 inch Fire Grate – Open Fire test results – COFFEE LOGS

Pollutant + Method (mg/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
Anthanthrene	Dilution tunnel	1.65	0.59	2.26	1.50
Benzo(a)Anthracene	Dilution tunnel	12.38	7.64	21.70	13.91
Benzo(a)pyrene	Dilution tunnel	12.72	6.55	17.25	12.17
Benzo(b)fluoranthene	Dilution tunnel	6.79	3.69	10.88	7.12
Benzo(b)naptho(2,1-d)thiophene	Dilution tunnel	0.41	0.18	0.39	0.32
Benzo(c)phenanthrene	Dilution tunnel	3.79	2.04	6.27	4.03
Benzo(ghi)Perylene	Dilution tunnel	6.39	3.48	11.80	7.22
Benzo(k)fluoranthene	Dilution tunnel	3.27	1.74	6.03	3.68
Cholanthrene	Dilution tunnel	0.07	0.03	0.08	0.06
Chrysene	Dilution tunnel	16.57	10.41	25.34	17.44
Cyclopenta(cd)pyrene	Dilution tunnel	9.47	4.62	18.78	10.96
Dibenzo (ai) pyrene	Dilution tunnel	0.09	0.03	0.28	0.13
Dibenzo(ah)Anthracene	Dilution tunnel	1.11	0.56	1.78	1.15
Fluoranthene	Dilution tunnel	49.97	30.60	85.69	55.42
Indeno(123-cd)Pyrene	Dilution tunnel	7.15	3.60	12.76	7.84
Naphthalene	Dilution tunnel	1671.95	811.64	2650.82	1711.47
Total (Excluding Non-Detects)	Dilution tunnel	1803.77	887.39	2872.10	1854.42
Total (Including Non-Detects)	Dilution tunnel	1803.77	887.39	2872.10	1854.42
LRTAP PAH total	Dilution tunnel	29.93	15.58	46.93	30.81

A.6 POLLUTANT MEASUREMENTS DATASET – HEAVY METALS

Table A-59 : Charnwood C-4 blu – Modern Stove test results – COAL

Pollutant + Method (mg/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
Antimony	Dilution tunnel	5.84	3.48	2.26	3.86
Arsenic	Dilution tunnel	2.28	2.78	3.25	2.77
Cadmium	Dilution tunnel	2.23	2.17	1.86	2.09

Chromium	Dilution tunnel	459.68	3488.89	105.77	1351.44
Cobalt	Dilution tunnel	1.60	1.96	1.72	1.76
Copper	Dilution tunnel	26.02	23.19	34.59	27.93
Lead	Dilution tunnel	41.25	24.37	19.70	28.44
Manganese	Dilution tunnel	12.57	13.25	14.08	13.30
Mercury	Dilution tunnel	1.57	1.90	2.13	1.87
Nickel	Dilution tunnel	60.25	123.92	54.64	79.60
Selenium	Dilution tunnel	2.81	3.43	3.02	3.09
Thallium	Dilution tunnel	1.46	1.65	1.58	1.56
Vanadium	Dilution tunnel	4.17	2.35	1.80	2.77
Zinc	Dilution tunnel	121.49	158.73	304.17	194.80

Table 00-60 : Charnwood C-4 blu – Modern Stove test results – ANTHRACITE

Pollutant + Method (mg/GJ net)	**Measurement location**	**Run 1**	**Run 2**	**Run 3**	**Average**
Antimony	Dilution tunnel	2.01	2.56	1.65	2.07
Arsenic	Dilution tunnel	27.87	23.05	3.72	18.21
Cadmium	Dilution tunnel	2.01	2.31	1.42	1.92
Chromium	Dilution tunnel	73.02	80.64	38.70	64.12
Cobalt	Dilution tunnel	1.52	1.56	1.42	1.50
Copper	Dilution tunnel	16.84	8.58	4.67	10.03
Lead	Dilution tunnel	36.36	93.73	11.68	47.26
Manganese	Dilution tunnel	11.13	13.17	8.49	10.93
Mercury	Dilution tunnel	4.18	8.31	2.02	4.84
Nickel	Dilution tunnel	85.48	62.67	57.35	68.50
Selenium	Dilution tunnel	6.79	7.61	2.55	5.65
Thallium	Dilution tunnel	1.28	1.56	1.19	1.34
Vanadium	Dilution tunnel	4.09	2.40	1.97	2.82
Zinc	Dilution tunnel	200.38	245.50	38.94	161.61

Table A-61 : Charnwood C-4 blu – Modern Stove test results – Low Sulphur MSF

Pollutant + Method (mg/GJ net)	**Measurement location**	**Run 1**	**Run 2**	**Run 3**	**Average**

Antimony	Dilution tunnel	3.26	2.96	4.00	3.41
Arsenic	Dilution tunnel	8.73	7.87	3.68	6.76
Cadmium	Dilution tunnel	2.23	2.30	2.46	2.33
Chromium	Dilution tunnel	44.10	44.31	12433.78	4174.06
Cobalt	Dilution tunnel	2.23	2.24	4.00	2.82
Copper	Dilution tunnel	30.43	13.16	8.20	17.26
Lead	Dilution tunnel	43.89	45.00	15.03	34.64
Manganese	Dilution tunnel	13.34	8.15	21.79	14.43
Mercury	Dilution tunnel	4.20	4.26	2.27	3.58
Nickel	Dilution tunnel	89.57	92.29	185.84	122.57
Selenium	Dilution tunnel	5.64	5.64	4.85	5.38
Thallium	Dilution tunnel	2.23	2.24	2.07	2.18
Vanadium	Dilution tunnel	12.30	9.21	8.19	9.90
Zinc	Dilution tunnel	44.20	55.38	75.80	58.46

Table A-62 : Charnwood C-4 blu – Modern Stove test results – High Sulphur MSF

Pollutant + Method (mg/GJ net)	**Measurement location**	**Run 1**	**Run 2**	**Run 3**	**Average**
Antimony	Dilution tunnel	2.45	3.38	2.64	2.82
Arsenic	Dilution tunnel	2.65	3.41	3.78	3.28
Cadmium	Dilution tunnel	2.11	2.56	2.27	2.32
Chromium	Dilution tunnel	38.89	2035.21	6169.31	2747.80
Cobalt	Dilution tunnel	2.11	2.56	2.27	2.32
Copper	Dilution tunnel	16.64	18.01	18.34	17.66
Lead	Dilution tunnel	50.32	45.78	43.82	46.64
Manganese	Dilution tunnel	10.80	9.69	11.89	10.79
Mercury	Dilution tunnel	1.91	2.39	2.35	2.22
Nickel	Dilution tunnel	82.55	96.42	83.78	87.58
Selenium	Dilution tunnel	3.64	4.42	3.92	3.99
Thallium	Dilution tunnel	2.11	2.56	3.00	2.56
Vanadium	Dilution tunnel	16.40	13.78	11.48	13.88
Zinc	Dilution tunnel	50.24	79.26	98.94	76.15

Table A-63 : Charnwood C-4 blu – Modern Stove test results – COFFEE LOGS

Pollutant + Method (mg/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
Antimony	Dilution tunnel	2.19	3.12	2.93	2.75
Arsenic	Dilution tunnel	2.35	3.98	3.18	3.17
Cadmium	Dilution tunnel	2.19	3.55	2.93	2.89
Chromium	Dilution tunnel	25.31	1890.24	406.27	773.94
Cobalt	Dilution tunnel	1.89	2.70	2.54	2.37
Copper	Dilution tunnel	36.20	64.10	9.44	36.58
Lead	Dilution tunnel	169.74	189.61	97.62	152.32
Manganese	Dilution tunnel	9.09	11.82	12.86	11.26
Mercury	Dilution tunnel	1.91	2.77	2.39	2.35
Nickel	Dilution tunnel	163.45	247.18	131.28	180.64
Selenium	Dilution tunnel	3.25	4.68	4.43	4.12
Thallium	Dilution tunnel	1.59	2.46	2.14	2.06
Vanadium	Dilution tunnel	1.45	4.11	2.66	2.74
Zinc	Dilution tunnel	48.99	87.59	431.55	189.37

Table A-64 : Dovre 500MRF Cast Iron Stove test results – COAL

Pollutant + Method (mg/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
Antimony	Dilution tunnel	1.39	1.54	2.02	1.65
Arsenic	Dilution tunnel	1.40	115.19	29.47	48.69
Cadmium	Dilution tunnel	1.20	1.32	1.37	1.30
Chromium	Dilution tunnel	107.11	22.31	52.80	60.74
Cobalt	Dilution tunnel	1.20	1.54	2.46	1.73
Copper	Dilution tunnel	8.56	8.35	24969.57	8328.83
Lead	Dilution tunnel	5.00	6.96	15.14	9.03
Manganese	Dilution tunnel	7.93	8.12	285.81	100.62
Mercury	Dilution tunnel	1.30	4.23	1.59	2.37
Nickel	Dilution tunnel	74.12	89.73	26745.56	8969.80
Selenium	Dilution tunnel	2.06	2.22	4.55	2.94
Thallium	Dilution tunnel	1.01	2.99	1.25	1.75
Vanadium	Dilution tunnel	0.89	1.42	6.22	2.84
Zinc	Dilution tunnel	53.60	34.76	87.74	58.70

Table A-65 : Dovre 500MRF Cast Iron Stove test results – ANTHRACITE

Pollutant + Method (mg/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
Antimony	Dilution tunnel	2.41	11.58	1.68	5.22
Arsenic	Dilution tunnel	31.65	84.54	31.18	49.13
Cadmium	Dilution tunnel	1.66	4.21	1.86	2.58
Chromium	Dilution tunnel	21.16	1061.33	326.15	469.55
Cobalt	Dilution tunnel	1.03	2.10	1.15	1.43
Copper	Dilution tunnel	23.14	17.67	27.16	22.66
Lead	Dilution tunnel	97.48	103.79	60.46	87.24
Manganese	Dilution tunnel	5.52	18.61	6.54	10.22
Mercury	Dilution tunnel	2.43	8.14	3.66	4.74
Nickel	Dilution tunnel	69.36	70.47	82.25	74.03
Selenium	Dilution tunnel	9.53	18.03	10.68	12.75

Thallium	Dilution tunnel	1.78	3.15	1.32	2.09
Vanadium	Dilution tunnel	2.20	3.33	1.56	2.36
Zinc	Dilution tunnel	160.98	779.29	128.21	356.16

Table A-66 : Dovre 500MRF Cast Iron Stove test results – Low Sulphur MSF

Pollutant + Method (mg/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
Antimony	Dilution tunnel	1.52	1.37	1.42	1.44
Arsenic	Dilution tunnel	5.65	4.59	6.46	5.57
Cadmium	Dilution tunnel	1.31	1.17	1.23	1.24
Chromium	Dilution tunnel	21.00	16.45	44.01	27.15
Cobalt	Dilution tunnel	1.31	1.17	1.23	1.24
Copper	Dilution tunnel	28.58	6.27	3.62	12.82
Lead	Dilution tunnel	44.22	29.54	48.21	40.66
Manganese	Dilution tunnel	5.74	4.29	3.35	4.46
Mercury	Dilution tunnel	2.72	0.95	2.55	2.07
Nickel	Dilution tunnel	82.63	60.93	54.40	65.99
Selenium	Dilution tunnel	4.85	3.67	5.03	4.52
Thallium	Dilution tunnel	1.94	1.36	2.00	1.77
Vanadium	Dilution tunnel	7.25	6.61	8.03	7.30
Zinc	Dilution tunnel	32.42	44.34	53.26	43.34

Table A-67 : Dovre 500MRF Cast Iron Stove test results – High Sulphur MSF

Pollutant + Method (mg/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
Antimony	Dilution tunnel	1.74	1.87	2.06	1.89
Arsenic	Dilution tunnel	2.55	3.34	4.12	3.33
Cadmium	Dilution tunnel	1.74	1.63	2.62	1.99
Chromium	Dilution tunnel	18.50	34.37	40.24	31.04
Cobalt	Dilution tunnel	1.50	1.63	1.78	1.63
Copper	Dilution tunnel	6.86	12.32	17.52	12.23
Lead	Dilution tunnel	32.15	27.23	42.85	34.08
Manganese	Dilution tunnel	6.45	7.22	11.01	8.23

Mercury	Dilution tunnel	1.59	1.70	1.96	1.75
Nickel	Dilution tunnel	46.28	47.57	103.43	65.76
Selenium	Dilution tunnel	3.77	4.02	4.50	4.10
Thallium	Dilution tunnel	2.22	2.12	2.62	2.32
Vanadium	Dilution tunnel	12.94	19.06	22.24	18.08
Zinc	Dilution tunnel	52.69	67.37	74.35	64.80

Table A-68 : Dovre 500MRF Cast Iron Stove test results – COFFEE LOGS

Pollutant + Method (mg/GJ net)	**Measurement location**	**Run 1**	**Run 2**	**Run 3**	**Average**
Antimony	Dilution tunnel	1.07	1.47	1.47	1.34
Arsenic	Dilution tunnel	10.23	9.18	5.39	8.27
Cadmium	Dilution tunnel	1.25	1.66	1.66	1.53
Chromium	Dilution tunnel	129.48	1317.93	396.51	614.64
Cobalt	Dilution tunnel	0.93	1.27	1.28	1.16
Copper	Dilution tunnel	55.70	23.85	21.51	33.69
Lead	Dilution tunnel	127.87	160.88	148.26	145.67
Manganese	Dilution tunnel	7.35	8.64	7.43	7.80
Mercury	Dilution tunnel	0.81	1.16	1.33	1.10
Nickel	Dilution tunnel	81.94	73.53	65.73	73.73
Selenium	Dilution tunnel	1.60	2.22	2.30	2.04
Thallium	Dilution tunnel	0.78	1.07	1.21	1.02
Vanadium	Dilution tunnel	4.08	2.51	1.88	2.83
Zinc	Dilution tunnel	74.60	144.61	100.18	106.46

Table A-69 : Hunter Oakwood Stove test results – COAL

Pollutant + Method (mg/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
Antimony	Dilution tunnel	1.64	1.81	1.68	1.71
Arsenic	Dilution tunnel	1.71	1.89	1.75	1.78
Cadmium	Dilution tunnel	1.45	1.61	1.48	1.51
Chromium	Dilution tunnel	49.67	48.84	17.45	38.65
Cobalt	Dilution tunnel	1.45	1.61	1.48	1.51
Copper	Dilution tunnel	9.84	6.44	6.97	7.75
Lead	Dilution tunnel	11.17	5.86	7.12	8.05
Manganese	Dilution tunnel	3.32	4.59	3.42	3.78
Mercury	Dilution tunnel	3.32	3.68	3.40	3.46
Nickel	Dilution tunnel	48.44	59.02	52.60	53.35
Selenium	Dilution tunnel	2.85	3.16	2.92	2.98
Thallium	Dilution tunnel	1.26	1.40	1.29	1.32
Vanadium	Dilution tunnel	1.62	1.11	1.03	1.26
Zinc	Dilution tunnel	41.21	48.77	30.42	40.13

Table A-70 : Hunter Oakwood Stove test results – ANTHRACITE

Pollutant + Method (mg/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
Antimony	Dilution tunnel	2.78	2.92	2.86	2.85
Arsenic	Dilution tunnel	29.25	61.44	49.07	46.59
Cadmium	Dilution tunnel	2.11	2.48	1.97	2.19
Chromium	Dilution tunnel	241.15	167.68	33.47	147.43
Cobalt	Dilution tunnel	1.78	1.59	1.44	1.60
Copper	Dilution tunnel	15.80	8.34	25.38	16.51
Lead	Dilution tunnel	93.96	89.38	80.89	88.08
Manganese	Dilution tunnel	9.67	11.11	11.09	10.62
Mercury	Dilution tunnel	3.63	4.98	4.17	4.26
Nickel	Dilution tunnel	60.74	54.34	77.49	64.19
Selenium	Dilution tunnel	7.27	10.45	12.08	9.93
Thallium	Dilution tunnel	1.45	1.59	1.26	1.43

Vanadium	Dilution tunnel	1.89	4.13	2.77	2.93
Zinc	Dilution tunnel	138.97	292.65	118.93	183.52

Table A-71 : Hunter Oakwood Stove test results – Low Sulphur MSF

Pollutant + Method (mg/GJ net)	**Measurement location**	**Run 1**	**Run 2**	**Run 3**	**Average**
Antimony	Dilution tunnel	1.87	2.65	2.50	2.34
Arsenic	Dilution tunnel	8.39	4.54	7.71	6.88
Cadmium	Dilution tunnel	2.63	2.91	2.16	2.56
Chromium	Dilution tunnel	2396.84	18020.74	6124.24	8847.27
Cobalt	Dilution tunnel	1.61	12.82	2.16	5.53
Copper	Dilution tunnel	17.95	48.66	12.28	26.29
Lead	Dilution tunnel	49.64	26.35	37.12	37.70
Manganese	Dilution tunnel	10.27	12.51	8.39	10.39
Mercury	Dilution tunnel	3.43	2.53	3.79	3.25
Nickel	Dilution tunnel	88.87	155.71	120.07	121.55
Selenium	Dilution tunnel	5.73	3.84	5.78	5.11
Thallium	Dilution tunnel	2.12	1.70	2.16	1.99
Vanadium	Dilution tunnel	15.26	31.67	20.46	22.46
Zinc	Dilution tunnel	81.67	79.17	86.31	82.38

Table A-72 : Hunter Oakwood Stove test results – High Sulphur MSF

Pollutant + Method (mg/GJ net)	**Measurement location**	**Run 1**	**Run 2**	**Run 3**	**Average**
Antimony	Dilution tunnel	2.02	1.50	1.56	1.69
Arsenic	Dilution tunnel	9.36	5.12	5.62	6.70
Cadmium	Dilution tunnel	1.53	1.30	1.56	1.46
Chromium	Dilution tunnel	27.59	20.43	32.70	26.91
Cobalt	Dilution tunnel	2.02	1.30	1.34	1.55
Copper	Dilution tunnel	43.61	13.31	9.07	22.00
Lead	Dilution tunnel	35.82	22.11	37.77	31.90
Manganese	Dilution tunnel	20.54	4.60	7.03	10.72
Mercury	Dilution tunnel	1.43	1.37	1.58	1.46

Nickel	Dilution tunnel	151.60	80.09	113.69	115.13
Selenium	Dilution tunnel	3.62	2.64	3.46	3.24
Thallium	Dilution tunnel	2.02	1.50	1.77	1.76
Vanadium	Dilution tunnel	20.07	15.55	19.52	18.38
Zinc	Dilution tunnel	59.49	35.41	67.01	53.97

Table A-73 : Hunter Oakwood Stove test results – COFFEE LOGS

Pollutant + Method (mg/GJ net)	**Measurement location**	**Run 1**	**Run 2**	**Run 3**	**Average**
Antimony	Dilution tunnel	1.52	1.56	1.81	1.63
Arsenic	Dilution tunnel	2.61	2.41	1.78	2.27
Cadmium	Dilution tunnel	1.72	1.78	1.61	1.71
Chromium	Dilution tunnel	26.62	53.87	22.29	34.26
Cobalt	Dilution tunnel	1.31	1.35	1.22	1.29
Copper	Dilution tunnel	9.43	12.49	13.29	11.74
Lead	Dilution tunnel	22.18	21.17	15.02	19.46
Manganese	Dilution tunnel	15.91	22.60	15.02	17.85
Mercury	Dilution tunnel	1.31	1.21	1.13	1.22
Nickel	Dilution tunnel	67.28	79.20	64.14	70.21
Selenium	Dilution tunnel	2.28	2.31	2.08	2.22
Thallium	Dilution tunnel	1.10	1.13	1.02	1.09
Vanadium	Dilution tunnel	3.93	3.02	2.96	3.30
Zinc	Dilution tunnel	138.42	126.24	70.38	111.68

Table A-74 : Parkray Paragon 16 inch Fire Grate – Open Fire test results – COAL

Pollutant + Method (mg/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
Antimony	Dilution tunnel	1.12	0.82	1.37	1.10
Arsenic	Dilution tunnel	1.07	1.20	1.29	1.19
Cadmium	Dilution tunnel	0.97	0.70	1.18	0.95
Chromium	Dilution tunnel	17.85	12.68	19.20	16.57
Cobalt	Dilution tunnel	0.97	0.70	1.18	0.95
Copper	Dilution tunnel	12.95	99.00	17.63	43.19
Lead	Dilution tunnel	2.28	5.11	2.72	3.37
Manganese	Dilution tunnel	3.60	10.17	4.40	6.06
Mercury	Dilution tunnel	1.01	0.64	1.11	0.92
Nickel	Dilution tunnel	56.79	371.77	71.37	166.64
Selenium	Dilution tunnel	1.68	1.31	1.87	1.62
Thallium	Dilution tunnel	0.81	0.59	0.99	0.80
Vanadium	Dilution tunnel	4.08	3.02	5.11	4.07
Zinc	Dilution tunnel	31.75	26.55	228.22	95.50

Table A-75 : Parkray Paragon 16 inch Fire Grate – Open Fire test results – Low Sulphur MSF

Pollutant + Method (mg/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
Antimony	Dilution tunnel	1.19	1.30	1.84	1.44
Arsenic	Dilution tunnel	6.94	5.93	7.59	6.82
Cadmium	Dilution tunnel	1.05	1.14	1.58	1.26
Chromium	Dilution tunnel	455.81	62.01	266.39	261.40
Cobalt	Dilution tunnel	0.90	0.98	1.58	1.16
Copper	Dilution tunnel	5.81	29.93	466.16	167.30
Lead	Dilution tunnel	57.46	54.41	61.36	57.74
Manganese	Dilution tunnel	4.79	4.54	16.16	8.50
Mercury	Dilution tunnel	2.28	2.13	3.08	2.50
Nickel	Dilution tunnel	48.87	70.08	888.16	335.70
Selenium	Dilution tunnel	6.30	6.03	8.93	7.08
Thallium	Dilution tunnel	1.92	1.92	2.87	2.24

Vanadium	Dilution tunnel	15.68	7.29	9.68	10.88
Zinc	Dilution tunnel	33.02	44.26	47.37	41.55

Table A-76 : Parkray Paragon 16 inch Fire Grate – Open Fire test results – High Sulphur MSF

Pollutant + Method (mg/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
Antimony	Dilution tunnel	3.31	1.37	1.37	2.02
Arsenic	Dilution tunnel	5.78	1.28	1.86	2.97
Cadmium	Dilution tunnel	3.31	1.18	1.18	1.89
Chromium	Dilution tunnel	98.01	13.33	20.42	43.92
Cobalt	Dilution tunnel	2.85	1.18	1.18	1.74
Copper	Dilution tunnel	22.90	5.68	8.59	12.39
Lead	Dilution tunnel	69.33	3.92	25.67	32.97
Manganese	Dilution tunnel	22.76	4.90	5.33	11.00
Mercury	Dilution tunnel	2.93	0.91	1.09	1.64
Nickel	Dilution tunnel	148.10	48.01	50.65	82.26
Selenium	Dilution tunnel	8.11	1.97	3.35	4.47
Thallium	Dilution tunnel	4.66	0.98	1.74	2.46
Vanadium	Dilution tunnel	79.45	17.05	21.43	39.31
Zinc	Dilution tunnel	95.73	18.22	36.43	50.13

Table A-77 : Parkray Paragon 16 inch Fire Grate – Open Fire test results – COFFEE LOGS

Pollutant + Method (mg/GJ net)	Measurement location	Run 1	Run 2	Run 3	Average
Antimony	Dilution tunnel	1.21	0.99	1.33	1.18
Arsenic	Dilution tunnel	1.57	1.07	1.44	1.36
Cadmium	Dilution tunnel	1.38	0.81	1.15	1.11
Chromium	Dilution tunnel	495.79	1178.22	163.22	612.41
Cobalt	Dilution tunnel	1.05	0.81	1.15	1.00
Copper	Dilution tunnel	3.42	16.26	72.85	30.85
Lead	Dilution tunnel	4.70	5.38	7.84	5.97
Manganese	Dilution tunnel	9.68	5.25	8.76	7.90
Mercury	Dilution tunnel	0.97	0.73	1.01	0.90

Nickel	Dilution tunnel	8.56	37.25	150.89	65.57
Selenium	Dilution tunnel	1.81	1.37	1.96	1.71
Thallium	Dilution tunnel	0.88	0.68	0.96	0.84
Vanadium	Dilution tunnel	2.10	1.65	2.15	1.97
Zinc	Dilution tunnel	29.14	215.83	220.55	155.17

A.7 POLLUTANT MEASUREMENTS DATASET - HEAVY METALS DETAIL

Table A-78 : Heavy Metals Test Results - Coal

Pollutant (mg/GJ net)	Modern Stove			Dovre Stove			Hunter Oakwood Stove			Open Fire		
	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3
Antimony	5.84	3.48	2.26	1.39	1.54	2.02	1.64	1.81	1.68	1.12	0.82	1.37
Arsenic	2.28	2.78	3.25	1.40	115.19	29.47	1.71	1.89	1.75	1.07	1.20	1.29
Cadmium	2.23	2.17	1.86	1.20	1.32	1.37	1.45	1.61	1.48	0.97	0.70	1.18
Chromium	459.68	3488.89	105.77	107.11	22.31	52.80	49.67	48.84	17.45	17.85	12.68	19.20
Cobalt	1.60	1.96	1.72	1.20	1.54	2.46	1.45	1.61	1.48	0.97	0.70	1.18
Copper	26.02	23.19	34.59	8.56	8.35	24969.57	9.84	6.44	6.97	12.95	99.00	17.63
Lead	41.25	24.37	19.70	5.00	6.96	15.14	11.17	5.86	7.12	2.28	5.11	2.72
Manganese	12.57	13.25	14.08	7.93	8.12	285.81	3.32	4.59	3.42	3.60	10.17	4.40
Mercury	1.57	1.90	2.13	1.30	4.23	1.59	3.32	3.68	3.40	1.01	0.64	1.11
Nickel	60.25	123.92	54.64	74.12	89.73	26745.56	48.44	59.02	52.60	56.79	371.77	71.37
Selenium	2.81	3.43	3.02	2.06	2.22	4.55	2.85	3.16	2.92	1.68	1.31	1.87
Thallium	1.46	1.65	1.58	1.01	2.99	1.25	1.26	1.40	1.29	0.81	0.59	0.99
Vanadium	4.17	2.35	1.80	0.89	1.42	6.22	1.62	1.11	1.03	4.08	3.02	5.11
Zinc	121.49	158.73	304.17	53.60	34.76	87.74	41.21	48.77	30.42	31.75	26.55	228.22

Table A-79 : Heavy Metals Test Results – Anthracite

Pollutant (mg/GJ net)	Modern Stove			Dovre Stove			Hunter Oakwood Stove		
	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3
Antimony	2.01	2.56	1.65	2.41	11.58	1.68	2.78	2.92	2.86
Arsenic	27.87	23.05	3.72	31.65	84.54	31.18	29.25	61.44	49.07
Cadmium	2.01	2.31	1.42	1.66	4.21	1.86	2.11	2.48	1.97
Chromium	73.02	80.64	38.70	21.16	1061.33	326.15	241.15	167.68	33.47
Cobalt	1.52	1.56	1.42	1.03	2.10	1.15	1.78	1.59	1.44
Copper	16.84	8.58	4.67	23.14	17.67	27.16	15.80	8.34	25.38
Lead	36.36	93.73	11.68	97.48	103.79	60.46	93.96	89.38	80.89
Manganese	11.13	13.17	8.49	5.52	18.61	6.54	9.67	11.11	11.09
Mercury	4.18	8.31	2.02	2.43	8.14	3.66	3.63	4.98	4.17
Nickel	85.48	62.67	57.35	69.36	70.47	82.25	60.74	54.34	77.49
Selenium	6.79	7.61	2.55	9.53	18.03	10.68	7.27	10.45	12.08
Thallium	1.28	1.56	1.19	1.78	3.15	1.32	1.45	1.59	1.26
Vanadium	4.09	2.40	1.97	2.20	3.33	1.56	1.89	4.13	2.77
Zinc	200.38	245.50	38.94	160.98	779.29	128.21	138.97	292.65	118.93

Table A-80 : Heavy Metals Test Results – Low Sulphur MSF

Pollutant (mg/GJ net)	Modern Stove			Dovre Stove			Hunter Oakwood Stove			Open Fire		
	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3
Antimony	3.26	2.96	4.00	1.52	1.37	1.42	1.87	2.65	2.50	1.19	1.30	1.84
Arsenic	8.73	7.87	3.68	5.65	4.59	6.46	8.39	4.54	7.71	6.94	5.93	7.59
Cadmium	2.23	2.30	2.46	1.31	1.17	1.23	2.63	2.91	2.16	1.05	1.14	1.58
Chromium	44.10	44.31	12433.78	21.00	16.45	44.01	2396.84	18020.74	6124.24	455.81	62.01	266.39
Cobalt	2.23	2.24	4.00	1.31	1.17	1.23	1.61	12.82	2.16	0.90	0.98	1.58
Copper	30.43	13.16	8.20	28.58	6.27	3.62	17.95	48.66	12.28	5.81	29.93	466.16
Lead	43.89	45.00	15.03	44.22	29.54	48.21	49.64	26.35	37.12	57.46	54.41	61.36
Manganese	13.34	8.15	21.79	5.74	4.29	3.35	10.27	12.51	8.39	4.79	4.54	16.16
Mercury	4.20	4.26	2.27	2.72	0.95	2.55	3.43	2.53	3.79	2.28	2.13	3.08
Nickel	89.57	92.29	185.84	82.63	60.93	54.40	88.87	155.71	120.07	48.87	70.08	888.16
Selenium	5.64	5.64	4.85	4.85	3.67	5.03	5.73	3.84	5.78	6.30	6.03	8.93
Thallium	2.23	2.24	2.07	1.94	1.36	2.00	2.12	1.70	2.16	1.92	1.92	2.87
Vanadium	12.30	9.21	8.19	7.25	6.61	8.03	15.26	31.67	20.46	15.68	7.29	9.68
Zinc	44.20	55.38	75.80	32.42	44.34	53.26	81.67	79.17	86.31	33.02	44.26	47.37

Table A-81 : Heavy Metals Test Results – High Sulphur MSF

Pollutant	Modern Stove			Dovre Stove			Hunter Oakwood Stove			Open Fire		
(mg/GJ net)	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3
Antimony	2.45	3.38	2.64	1.74	1.87	2.06	2.02	1.50	1.56	3.31	1.37	1.37
Arsenic	2.65	3.41	3.78	2.55	3.34	4.12	9.36	5.12	5.62	5.78	1.28	1.86
Cadmium	2.11	2.56	2.27	1.74	1.63	2.62	1.53	1.30	1.56	3.31	1.18	1.18
Chromium	38.89	2035.21	6169.31	18.50	34.37	40.24	27.59	20.43	32.70	98.01	13.33	20.42
Cobalt	2.11	2.56	2.27	1.50	1.63	1.78	2.02	1.30	1.34	2.85	1.18	1.18
Copper	16.64	18.01	18.34	6.86	12.32	17.52	43.61	13.31	9.07	22.90	5.68	8.59
Lead	50.32	45.78	43.82	32.15	27.23	42.85	35.82	22.11	37.77	69.33	3.92	25.67
Manganese	10.80	9.69	11.89	6.45	7.22	11.01	20.54	4.60	7.03	22.76	4.90	5.33
Mercury	1.91	2.39	2.35	1.59	1.70	1.96	1.43	1.37	1.58	2.93	0.91	1.09
Nickel	82.55	96.42	83.78	46.28	47.57	103.43	151.60	80.09	113.69	148.10	48.01	50.65
Selenium	3.64	4.42	3.92	3.77	4.02	4.50	3.62	2.64	3.46	8.11	1.97	3.35
Thallium	2.11	2.56	3.00	2.22	2.12	2.62	2.02	1.50	1.77	4.66	0.98	1.74
Vanadium	16.40	13.78	11.48	12.94	19.06	22.24	20.07	15.55	19.52	79.45	17.05	21.43
Zinc	50.24	79.26	98.94	52.69	67.37	74.35	59.49	35.41	67.01	95.73	18.22	36.43

Table A-82 : Heavy Metals Test Results – Coffee Logs

Pollutant (mg/GJ net)	Modern Stove			Dovre Stove			Hunter Oakwood Stove			Open Fire		
	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3
Antimony	2.19	3.12	2.93	1.07	1.47	1.47	1.52	1.56	1.81	1.21	0.99	1.33
Arsenic	2.35	3.98	3.18	10.23	9.18	5.39	2.61	2.41	1.78	1.57	1.07	1.44
Cadmium	2.19	3.55	2.93	1.25	1.66	1.66	1.72	1.78	1.61	1.38	0.81	1.15
Chromium	25.31	1890.24	406.27	129.48	1317.93	396.51	26.62	53.87	22.29	495.79	1178.22	163.22
Cobalt	1.89	2.70	2.54	0.93	1.27	1.28	1.31	1.35	1.22	1.05	0.81	1.15
Copper	36.20	64.10	9.44	55.70	23.85	21.51	9.43	12.49	13.29	3.42	16.26	72.85
Lead	169.74	189.61	97.62	127.87	160.88	148.26	22.18	21.17	15.02	4.70	5.38	7.84
Manganese	9.09	11.82	12.86	7.35	8.64	7.43	15.91	22.60	15.02	9.68	5.25	8.76
Mercury	1.91	2.77	2.39	0.81	1.16	1.33	1.31	1.21	1.13	0.97	0.73	1.01
Nickel	163.45	247.18	131.28	81.94	73.53	65.73	67.28	79.20	64.14	8.56	37.25	150.89
Selenium	3.25	4.68	4.43	1.60	2.22	2.30	2.28	2.31	2.08	1.81	1.37	1.96
Thallium	1.59	2.46	2.14	0.78	1.07	1.21	1.10	1.13	1.02	0.88	0.68	0.96
Vanadium	1.45	4.11	2.66	4.08	2.51	1.88	3.93	3.02	2.96	2.10	1.65	2.15
Zinc	48.99	87.59	431.55	74.60	144.61	100.18	138.42	126.24	70.38	29.14	215.83	220.55

A.8 COMPARISON OF EFDSF PROJECT TEST PARAMETERS AND SELECTED LITERATURE

Paper/study	EIG 2019	Appliance type	Size, kW	Fuel	Cold Ignition	Refuel	Burnout	Repeat tests	Fuel Moisture, %	Calorific value	Test duration	Fuel load	Comments
EFDSF project	**No**	Open fire Stove (1997) Stove (2008, EN 13240) Stove (Ecodesign 2020)		Coal, anthracite, MSF, coffee logs Coal, anthracite, MSF, coffee logs Coal, anthracite, MSF, coffee logs Coal, anthracite, MSF, coffee logs	Y	1-3	Y	3	Reported	Reported	~240 min	Recorded	All appliances given same approx. fuel load Open fire and older stoves are multifuel devices
The GB 2019 (EIG) references are mainly to the 2006 EIG		Open fire, Stove, Advanced stove, Boiler	Unknown	Solid fuels (except biomass)	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	All emission factors for stoves and open fire except Black Carbon and HCB refer to the 2006 version of Guidebook where references are unclear.
Trubetskaya et al (2021)	No	Conventional, multifuel stove Ecodesign, Waterford Stanley **prototype**	A nominal heat output of 11 kW with a nominal output of 9 kW	Wood logs, TOS briquettes, peat, ecobrite briquettes, smoky coal and firelighter TOS briquettes, ecobrite briquettes, smoky coal	Y Y	N N	Y Y	At least twice At least twice	15.7 (logs) 15.7 (logs)		2 to 4 hr 2 to 4 hr	For each combustion experiment, ≈3.5 kg of solid fuel and 100 g of solid firelighter (TESCO, Ireland) were placed in the stove. As above	Ireland study, appears to be a single batch Prototype unit

Paper/study	EIG 2019	Appliance type	Size, kW	Fuel	Cold Ignition	Refuel	Burnout	Repeat tests	Fuel Moisture, %	Calorific value	Test duration	Fuel load	Comments
		multifuel stove											
Atiku et al (2016)	No	A fixed bed stove (manufactured by Waterford Stanley Oisin)	maximum non-boiler thermal output of 5.7 kW load	Wood, Torrefied briquettes, Peat Briquettes, Coal, Biomass blend, Low smoke fuel, Smokeless fuel	?	?	?	N	Wood: ~8 wt% Torrefied wood: ~5% Coal: ~7% Peat: ~7% Others: ~2-6%		90 mins	?	Methodology follows EN 13240, not explained in detail in the paper
Křůmal et al 2019	No	Overfire boiler (B1), boiler with down-draft combustion (B2), gasification boiler (B3) and automatic boiler (B4)	B1: 25kW B2: 32kW B3: 25kW	Dry spruce wood (DW), wet spruce wood (WW), wood pellets (WP), brown coal (BC), brown coal briquettes (BCB) and hard coal (HC)	N	Y	N	The combustion tests for each setting were repeated three times.	Moisture content Brown coal: 25% Hard coal: 5%	Brown coal:19.8 MJ/kg Hard coal: 28.2 MJ/kg Not sure if gross or net	About 4.5h (minimum 4:03, maximum 6:02)	After establishing the initial period, fuel was added in amounts equal to 100, 60 or 30 % of the nominal output, and the boiler was operated at this output via the regulation of the combustion air supply	Not a stove.
Maxwell et al 2020	No	fixed bed stove (Waterford and Stanley Oisin)	5.7kW	Norway Spruce Torrefied spruce briquettes Willow logs Torrefied willow briquettes	Y Emissions from ignition not used for EF calculations due to firelighters used.	Y 3 reloads	N	N	Norway Spruce: 18% Torrefied spruce briquettes: 4.6% Willow logs: 10%		~150 minutes	0.7-0.9 kg	No mineral fuels.

Paper/study	EIG 2019	Appliance type	Size, kW	Fuel	Cold Ignition	Refuel	Burnout	Repeat tests	Fuel Moisture, %	Calorific value	Test duration	Fuel load	Comments
				Olive stone Torrefied olive stone briquettes					Torrefied willow briquettes: 7.6% Olive stone:14.8 % Torrefied olive stone briquettes: 6.4%				
Lee et al 2005	Y	Fuels were burnt in an open fire test setting and chimney as described in BS3841: Part 1: 1994	?	Housecoal Seasoned hardwood	Y	Y.	N Test terminated when radiant output reached 1.45kW	Unknown	Housecoal : 2.2% Seasoned hardwood: 10.8%	GCV Housecoal : 33,360 kJ/kg Seasoned hardwood: 1880 kJ/kg	The fire was allowed to burn through a second and third radiation peak and on the radiant output reducing to 1.45 kW, the test was terminated ,	Wood: Initial charge of 2.8-3.0kg. Refuel charges 1.8-2.8kg Coal fuel load unknown	The test method described in BS3841: Part 1 is intended for coal-based fuels. For wood tests seven or eight refuels were done.
Roy et al. 2012	No	a Drolet XV EPA residential wood stove	Unknown	12 types of Biomass Briquette. Three types of wood for comparison (see below for detail)	No	None	No	Three tests	Briquettes between 3.25% (Canawick log) and 9.80% (Smartlog) . (See below for detail) Wood 7.23% to 8.80%	GCV Briquettes between 16.85 MJ/kg (Switchgrass) and 31.46 MJ/kg (Northland) Wood 17.08 MJ/kg to	2 minutes after steady state for gas. 30 minutes for PM	4.5-5kg	No mineral fuels.

Paper/study	EIG 2019	Appliance type	Size, kW	Fuel	Cold Ignition	Refuel	Burnout	Repeat tests	Fuel Moisture, %	Calorific value	Test duration	Fuel load	Comments
										18.16 MJ/kg			
Broderick et al. 2005	Yes	Masonry and factory-built fireplaces, with open/closed doors	Unknown	Dimensional lumber, cordwood	Unknown	Unknown	Unknown	Multiple sources of data were used. Some of the tests reviewed collected sample over only parts of fires, some tests used novel test methods or used research appliances, etc.	Unknown	Unknown	Unknown	Unknown	Multiple (US) appliances. No mineral fuels.
Limousy et. Al. 2015	No	The combustion experiments were carried out with a cast-iron wood stove (Lorflam, XP68) at the test bench of the Lorflam Company	8-12Kw	Spent coffee grounds (20%)/pine sawdust(80%) log Beech wood log SCG/Sawdust log with Beech wood log	No	No	No	Unknown	SCG/Saw dust log :10% Beech wood log: 17%	NCV SCG/sawdust log: 17386 kJ/kg Beech log: 14557 kJ/kg	45 minutes	1.8-2.4kg	Coffee grounds and wood fuels.
Limousy et. Al. 2013	No	12 kW boiler (Pellematic PES12 – PVB 2000) supplied by Ökofen (Barberaz, France) specifcally equipped for	12kW	Spent coffee grounds (SGC) pellets Pine pellets Blend of SGC and Pine (50/50wt%)	No	No	No	Unknown	SGC: 11.78% Pine: 7.9% Blend: 6.65% Blend lower moisture	SCG: GCV 19.55 kJ/kg NCV 17.52kJ/kg Pine: GCV 19.23kJ/kg	700 seconds	Unknown	Coffee grounds pellets and wood pellets.

Paper/study	EIG 2019	Appliance type	Size, kW	Fuel	Cold Ignition	Refuel	Burnout	Repeat tests	Fuel Moisture, %	Calorific value	Test duration	Fuel load	Comments
		combustion studies							% due to increased temperature during densification process	NCV 17.8kJ/kg Blend: GCV 19.63 kJ/kg NCV 17.91kJ/kg			
Paradiž et al. 2008	No	A commercial low-cost stove of Polish production was used for the combustion experiments. Despite of low cost the stove was of advanced design	Unknown	Commercial Polish hard coal	N	N	N	16	Unknown	30 MJ/kg	3 hours 45 minutes	5kg coal	Potential EN stove ?
Fott. 1999	No	n/a	n/a	Hard coal, brown coal	n/a	n/a	n/a	n/a	n/a	Hard coal 25.5 to 29.3 MJ/kg Brown coal 5.7 to 14.2 MJ/kg	n/a	n/a	Little detail
Kakareka et al. 2005	No	Russian stove Heating furnace Kitchen range Heating boiler KCHV-5	KCHV-5 20kW	Pine firewood, Birch firewood dry, Birch firewood damp, Peat briquette, Domestic wastes	Unknown	Unknown	Unknown	Three per fuel	Pine firewood: 13.6% Birch firewood dry: 9.8% Birch firewood damp: 37.4%	Net/Gross not specified Pine firewood: 18.3 MJ/kg Birch firewood dry: 19.8MJ/kg	Unknown	Unknown	Peat, waste fuel

Paper/study	EIG 2019	Appliance type	Size, kW	Fuel	Cold Ignition	Refuel	Burnout	Repeat tests	Fuel Moisture, %	Calorific value	Test duration	Fuel load	Comments
									Peat briquette: 16.5% Domestic wastes: 9.8%	Birch firewood damp: 13.7 MJ/kg Peat briquette: 17.6MJ/kg Domestic wastes: Not provided			
Smith et al. 2020	No	A fixed bed, multi-fuel stove with a nominal heat output of 11kW was used for all tests.	11kW	1. bituminous coal (doubles); 2. “smokeless” coal nuggets; 3. peat briquettes; 4. sod peat; 5. air-dried softwood logs; 6. kiln-dried hardwood logs. 7. Wet wood – limited number of tests so results indicative only	Y	N	Y	Y	Bituminous coal: 4.6% Smokeless coal: 17.3% Softwood (air-dried): 14.3% Hardwood: (kiln-dried): 6.2% Peat briquette: 13.1% Peat sod: 40.2%	GCV Bituminous coal: 34 MJ/kg Smokeless coal: 26.8 MJ/kg Softwood (Air-dried): 21.2 MJ/kg Hardwood (kiln-dried): 20MJ/kg Peat briquette: 23MJ/kg Peat sod: 23MJ/kg	The end of the test was defined as the time when the fuel consumption rate was asymptotically approaching zero: in general, the absolute consumption rate was below 1gmin–1 at the end of the test. Each test typically lasted between 4 and 7 hours.	3.5kg test fuel plus 100g firelighters For peat sod: 3kg test fuel, 500g kiln-dried kindling, 100g firelighters	Single batch (no refuel)
Trubetskaya et. Al	No	two stoves at University College Dublin (UCD),	Conventional: 11kW Ecodesign: 9kW	Wood logs TOS Briquettes	Y	N	Y	Y	Wood logs: 15.7%	19.2 MJ/kg 22.2 MJ/kg	2-4 Hours	~3.5kg fuel and 100g firelighters	Single batch

Paper/study	EIG 2019	Appliance type	Size, kW	Fuel	Cold Ignition	Refuel	Burnout	Repeat tests	Fuel Moisture, %	Calorific value	Test duration	Fuel load	Comments
		heretofore referred to as conventional and Ecodesign stoves		Peat Ecobrite briquettes Smoky coal Firelighter					Raw olive stones: 15.5% TOS Briquettes: 9.4% Peat: 26.5% Ecobrite: 6.3% Smoky coal: 1.3% Firelighter: 0%	24.3 MJ/kg 19.8 MJ/kg 32.8 MJ/kg 31.3 MJ/kg 35.9 MJ/kg			

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