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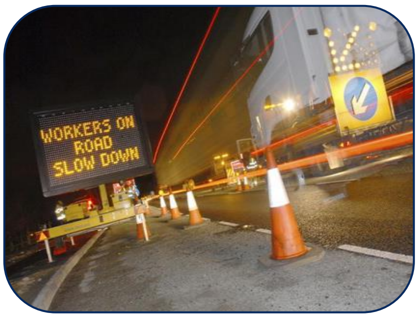

PUBLISHED PROJECT REPORT PPR574 (version 4.2)

Further guidance on the calculation of whole life cycle greenhouse gas emissions generated by asphalt

Part of the asphalt Pavement Embodied Carbon Tool (asPECT)

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with the advice of the Environmental Focus Group

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Document version history

This report has been amended and issued as follows:

Version	Date	Description	Editor	Technical Referee
1.0	20/10/09	TRL PPR440. Final version of guidance document covering cradle to installation.	MW	RG
2.0	27/09/10	Draft release of guidance document covering cradle to grave.	MW	HV
3.0	31/03/11	TRL PPR574. Final version of guidance document covering cradle to grave, meeting requirements of PAS 2050:2008.	MW	HV
4.0	07/02/14	TRL PPR574 (version 4.0). Final version of guidance document covering cradle to grave, meeting requirements of PAS 2050:2011.	MW	IC
4.1	16/12/14	TRL PPR574 (version 4.1). Final version of guidance document covering cradle to grave, meeting requirements of PAS 2050:2011 and incorporating feedback.	MW	IC
4.2	18/08/20	TRL PPR574 (version 4.2). Updated version to reflect the revised constants published in TRL PPR960, July 2020.	MW	DG

Contents

Foreword

This guidance document was first produced by the 2008-11 Collaborative Research Programme. It was subsequently reviewed and updated in 2013 and again in 2020 (this version). Collaborative research is a programme of work funded by Highways England (formerly the Highways Agency), Minerals Products Association, Eurobitume UK (formerly the Refined Bitumen Association). The remit of the original project was to create a consistent approach to measuring the contribution to climate change which highway products and applications make, and to achieve endorsement from the sector in doing so.

The regulatory context for greenhouse gas (GHG) reporting is becoming ever more challenging. Larger energy consumers now have to report carbon dioxide (CO_2) emissions to meet the requirements of the CRC Energy Efficiency Scheme; local authorities and local authority partnerships are required to report CO_2 emissions against a 2008-09 baseline in accordance with the National Indicator set (indicators 185 and 186), and uptake of the voluntary Carbon Disclosure Project, which has perhaps the most involved reporting requirements, is gathering pace. In addition to this, for client organisations, carbon awareness has translated into requirements for suppliers which are considered at the procurement stage and hence carbon has become another potential marketing tool for industry. It is hoped that the outputs of this project will assist in capturing the data that is required, and facilitates the necessary calculations for clients, industry and wider stakeholders for product level assessment.

This document accompanies the *Protocol for the Calculation of Whole Life Cycle Greenhouse Gas Emissions Generated by Asphalt* (*v4.2)* (Wayman *et al*., 2020). It is designed to provide extra interpretation and justification of the clauses within the protocol and to demonstrate how applicable sections of the *Publicly Available Specification for the Assessment of the Life Cycle Greenhouse Gas Emissions of Goods and Services* (PAS 2050:2011; British Standards institution, 2011) have been followed. Both the protocol and guidance documents also make reference to BEIS's *Greenhouse Gas Reporting: Conversion Factors* 2019. The normative references for these documents are *Environmental Management – Life Cycle Assessment – Requirements and Guidelines* (BS EN ISO 14044:2006) and the *Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006) respectively.

The accompanying asPECT software provides a framework which contains the necessary formulae, emissions factors and default data to calculate the GHG emissions of asphalt products in accordance with the protocol clauses and the information provided here. This guidance document, the protocol and the software constitute asphalt Pavement Embodied Carbon Tool (asPECT), and replaces version 4.1 delivered in 2014.

The asphalt life cycle includes the ten steps indicated in Figure 0.1. The protocol considers all emissions which contribute to climate change from sources including energy use, combustion processes, chemical reactions, service provision and delivery. By considering all life cycle emissions, the analysis constitutes a 'full life cycle GHG emissions assessment', as defined within the Publicly Available Specification (PAS) 2050:2011. The results of the assessment are therefore appropriate for business to consumer communications as well business to business communications in the supply chain. It is intended that manufacturers will make self-declarations of emissions in the first instance. These declarations can then be verified by third parties at a later date as required. The user can limit the scope of their emissions assessments to 'cradle-to-gate' or ‘cradle to installation’ by focussing on Steps 1-5 or 1-7 respectively (as long as the limits of the study are clearly communicated alongside the results).

Life-cycle stage		Description
1	**Raw Material Acquisition**	Acquiring raw materials from the natural environment with the input of energy
2	**Raw Material Transport**	Transporting acquired raw materials to processing
3	**Raw Material Processing**	Crude oil refining, rock crushing and grading, recycled and secondary material reprocessing
4	**Processed Material Transport**	Transporting processed raw materials to site of manufacture of bitumen bound highway components
5	**Road Component Production**	Production of bitumen bound mixtures
6	**Material Transport to Site**	Delivery of materials to site
7	**Installation**	Placing materials at the construction site, mobilisation of plant and labour
8	**Scheme Specific Works**	Installation of other specified materials direct to site (e.g. aggregates and geosystems)
9	**Maintenance**	Interventions to maintain the road: overlay, surface dressing works, patching, haunching etc.
10	**End of Life**	Excavation and material management, mobilisation of plant and labour

Use

Figure 0.1 Ten step asphalt life cycle indicating scope

The evaluation does not extend to consider use of materials over and above the pavement structure. This is because it is considered that use of the road by freight and passenger vehicles, and associated emissions, cannot be regulated and limited by the road designers and/or contractors, but instead depends on the number and types of vehicles using the road, as well as traffic conditions.

In addition to the commissioning partners, the protocol has been endorsed by ADEPT (Association of Directors of Environment, Economy, Planning and Transport) who participated extensively in its development.

In this document, the text of the protocol is presented in *Italics* for ease of reference.

0 Updates

2013 Update

The original project sponsors (the Highways Agency, Mineral Products Association and Refined Bitumen Association) commissioned a review of asPECT v3.0 in 2013. The remit of this review extended to the following four objectives:

a) To ensure that the approach now meets the requirements of *PAS 2050:2011 Specification for the assessment of the life cycle greenhouse gas emissions of goods and services* (British Standards Organisation, 2011), having previously met the requirements of PAS 2050:2008.

b) To consider how the approach meets the requirements of *ISO/TS 14067: Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification and communication* (International Standards Organisation, 2013).

c) To add additional functionality to the asPECT software, in order to facilitate the use of non-UK specific emissions factors for international users, and those requiring a more customisable approach with regards to recycling-recyclability allocation and consideration of residual binder activity.

d) To update specific emissions factors for materials (in Appendices C and D), and for fuels and transport in the software tool, where new and appropriate data sources have become available.

In relation to objective (a), the new version of the PAS has further reinforced the approach adopted in asPECT to introduce specific supplementary requirements for the asphalt sector. The PAS requires that supplementary requirements meet a series of criteria in order to be introduced. How asPECT meets these nine criteria is outlined in Appendix J. The approach used to assess emissions arising from recycling in asPECT is further justified by introduction of a closed-loop approximation method in PAS 2050:2011, alongside the pre-existing recycled content approach, and also the ability to introduce a specific approach to recycling through the aforementioned supplementary requirements.

Section 4.3 of the PAS justifies the introduction of supplementary requirements for specific sectors or products.

Annex D.3 of the PAS introduces a closed-loop approximation method for recycling alongside the pre-existing recycled content method in (now in Annex D.2). Adopting 'other types of recycling' through supplementary requirements is referred to in Annex D.5.

In terms of meeting the requirements of ISO 14067 (objective (b)), asPECT in its current form does not conflict with any of its requirements with regards to calculating carbon footprints. However, the ISO 14067 requirements with regards to interpretation, reporting and communication are additional to those of PAS2050:2011, hence asPECT only partially meets these requirements. Consequently, asPECT users wishing to fully meet the requirements of ISO 14067 should refer to the standard for particular stipulations regarding interpretation, reporting and communication of their asPECT generated results.

Clause 6.6 and Sections 7-9 of ISO 14067 state the requirements for interpreting, reporting and communicating the results of carbon footprint studies.

Additional functionality has been added to the asPECT software to meet objective (c). How to use this additional functionality is detailed in the accompanying *asPECT User Manual*.

To meet the requirements of objective (d), all emissions factors used throughout the asPECT documentation and software have been reviewed and updated where a newer, more applicable data source exists. Consequently, updated factors are now present in Appendix D of this Guidance and are incorporated in the asPECT software. The most significant update has been a switch to Defra's *Government Factors for Company Reporting*, released in 2014. All emission factors for fuel use, electricity, transport and material end-of-life processes have been brought up-to-date in line with this publication.

2020 update

The project sponsors (now Highways England, Eurobitume UK and the Mineral Products Association) commissioned a review of asPECT v4.1 in 2019. The remit of this review was to:

a) Undertake a review of asPECT to identify which areas of the tool need to be updated with more recent data and establishing what would be needed in order to transform asPECT into an Environmental Product Declaration (EPD) generator.

b) Update the constants file of the tool and appendices C and D of the 'protocol' and 'further guidance' documents with up-to-date values where available and modify the allocation of the benefits of recycled material in line with current standards.

Objective (a) is reported separately in PPR960 (Reeves et al, 2020). The findings of this review are being reviewed by the project sponsors to determine the next phase of development for asPECT.

To meet Objective (b), all emissions factors used throughout the asPECT documentation and software have been reviewed and, where a newer, more applicable data source existed, updated. The updated factors are present in Appendix D of this Guidance and are incorporated in the asPECT software. The most significant update has been a switch to *Greenhouse gas reporting: conversion factors 2019*, published by the Department for Business, Energy & Industrial Strategy (BEIS, 2019). All emission factors for fuel use, electricity, transport and material end-of-life processes have been brought up-to-date in line with this publication. Furthermore, the allocation of benefit associated with recycling asphalt has changed to 75:25 in favour of recycled content, replacing the previous 60:40 ratio. The ratio has been amended to further encourage closed-loop recycling to new asphalt mixtures, whilst still acknowledging that asphalt is fully recyclable and very rarely disposed of at end-of-life.

1 Scope

The protocol described in this document defines the methodologies which are to be applied to the calculation of carbon dioxide and other greenhouse gas (GHG) emissions from asphalt mixtures per tonne. The calculations are specific to individual mix formulations from individual production units incorporating all constituent materials. GHG contributions as carbon dioxide equivalents (CO_2e, to BSI PAS 2050:2011) are accounted for whether they are directly generated by the operator or indirectly by sub-contractors or suppliers.

The declaration for full life cycle GHG emissions assessments is made in terms of CO_2e per tonne of asphalt per year, which is the functional unit chosen for use in the protocol. To make full life cycle GHG emissions assessments, all sub-sections of Section 2 *must be followed. Partial life cycle GHG emissions assessments, in units of CO_2e per tonne, can also be produced by following distinct parts of Section* 2*. 'Cradle to gate' assessments can be made by following the requirements of Section 2.1 and 'cradle to site' assessments can be made by following both Sections 2.1 and 2.2.*

Explanatory Notes - Scope

What is CO_2e and why is it used?

The use of 'carbon dioxide equivalent' (CO_2e) recognises the fact that CO_2 is not the only greenhouse gas (GHG) and provides a way to reduce all GHGs to a single value for ease of comparison. Other GHGs are converted to CO_2e by multiplying the mass of a given GHG by its global warming potential (GWP).

Section 5.3 of the PAS specifies for the inclusion of non-CO_2 GHGs in an analysis.

Why are suppliers and sub-contractors emissions included?

A life cycle approach to calculating GHGs is taken. This allows the full contribution to climate change of a product incurred across its whole lifetime to be considered. The life cycle of a product extends across company boundaries.

Section 6 of the PAS specifies the requirements for setting the system boundary based on the life cycle of the product.

What is embodied CO_2e (or embodied carbon)?

In the context of asPECT, the embodied CO_2e is taken to mean the CO_2e which has been emitted in bringing the pavement and its constituent materials to the point of use. Embodied carbon contrasts with operational carbon which is emitted when the pavement is in use.

The functional unit is a tonne of asphalt, what if I need to calculate the CO_2e for a whole job?

The calculator software (which is also part of asPECT) includes the functionality to calculate the total CO_2e deriving from a given load, batch or consignment based on the per tonne CO_2e figures.

2 Requirements

2.1 Asphalt mixture

The CO_2e content of an individual asphalt mixture shall be calculated as the summation of the following elements:

- *The cradle to gate[1] CO_2e from each of the constituent materials and ancillary materials[2] calculated in accordance with Sections 2.4 to 2.6 (constCO_2e).*
- *The transport CO_2e from factory gate to mixing plant, calculated in accordance with Section 2.9 (transportCO_2e).*
- *CO_2e arising from all forms of energy involved in producing the asphalt at the mixing plant, other than that involved in heating and drying, but including energy for offices on site, calculated in accordance with Section 2.7 (plantCO_2e).*
- *CO_2e arising from the process of heating and drying the mixture and its constituent materials, calculated in accordance with Section 2.8 (heatCO_2e).*

$$\boldsymbol{CO_2e\ (asphalt\ mixture) = constCO_2e + transportCO_2e + plantCO_2e + heatCO_2e}$$

Equation 1

2.2 Asphalt application

In addition to the CO_2e content of an asphalt mixture, the following elements shall be included in the calculation to determine the CO_2e content of a given asphalt application:

- *CO_2e arising from transporting the asphalt material to site, calculated in accordance with Section 2.9.*
- *CO_2e associated with laying and compacting the material at the construction site (and related activities), calculated in accordance with Section 2.10.*
- *CO_2e associated with any additional materials used on site, calculated in accordance 2.11[3].*

2.3 Asphalt life time

When considering a full cradle to grave CO_2e assessment, the following elements shall be included:

- *An assessment of how long the asphalt will last from a design perspective, before being excavated, in accordance with Section 2.12.*
- *CO_2e associated with excavating the material at the end of life, in accordance with Section 2.13, and its onward transport in accordance with Section 2.9.*

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[1] 'Cradle to gate' is a term which describes the part of a product's lifetime from acquisition of raw materials through to the end of the manufacturing phase, the 'factory gate', where it is ready to be utilised.
[2] Ancillary materials are 'consumables' which are used in the manufacture of the final product but are not actually incorporated into it as a constituent. An example ancillary material would be explosives used in quarrying.
[3] Such materials can be included in overall application assessments but should not be attributed to the asphalt product cycle.

Exclusions

a. The manufacture, installation and maintenance of fixed plant are activities outside the remit of this protocol.

b. The manufacture and maintenance of mobile plant are activities outside the remit of this protocol.

c. Energy consumption from office and laboratory overheads shall be excluded from the calculation.

2.4 Cradle to gate constituent carbon dioxide equivalents in the mixture

The cradle to gate constituent CO_2e in a metric tonne of mixture shall be the summation of the delivered cradle to gate CO_2e of the constituents, used to make 100% of the mixture, apportioned on the basis of the plant batching instructions (mix recipe).

For the coarse and fine aggregate constituents (filler not included), quantities shall be increased by 5% in total to allow for moisture and wastage. For all other constituents, it shall be the actual percentage of the mixture. Therefore 105% of the coarse and fine fractions are sourced and transported to the asphalt plant but it is assumed that only 100% of the fractions are heated and mixed.

The delivered cradle to gate CO_2e of the constituents shall be calculated as described in Section 2.5.

Explanatory Notes - Requirements

What is the reason for the exclusions?

Whilst the construction of highways in itself represents a type of 'capital formation', capital goods (e.g. plant) used in the manufacture of asphalt as a product are excluded from product level assessments in accordance with the specification. Capital goods may be included in future revisions of the protocol as suitable data becomes available.

Section 6.4.4 of the PAS justifies the exclusion of capital goods within the calculation.

Corporate overheads (central offices and laboratories) are excluded from the product level assessment in this version of the protocol.

Why is 5% included as wastage (input only)?

5% is considered to be a reasonable estimate of aggregate which is lost as bag dust (extraction), aggregates left in bins and predominantly moisture (evaporated in the drying process), which are not used and are therefore wasted. If bag house fines are recovered and reused as filler then they are given a zero rating. Future versions of the protocol will consider more flexibility in the 5% figure if reliable data sources can demonstrate that this estimate may be inaccurate.

Worked Example - Requirements

Please note this example uses fictitious numbers. A simple mix recipe is as follows:

- Coarse aggregates: 785 kg = 78.5%
- Fine aggregates: 150 kg = 15%
- Filler: 15 kg = 1.5%
- Bitumen binder: 50 kg = 5%

Coarse and fine aggregates are transported by road in loads of 20 t from a quarry at 30 km from the asphalt plant. The trucks travel back empty from the asphalt plant to the quarry.

The filler used arises from the plant itself.

The bitumen is transported from a refinery at 100 km from the asphalt plant in tankers of 20 t capacity. The tankers travel back empty from the asphalt plant to the refinery.

The aggregates have the following cradle to gate CO_2e: 2.06 $kgCO_2e/t$.

The associated transport CO_2e is 69.96 $kgCO_2e$ /20 t (payload) = 3.50 $kgCO_2e/t$ (the example in Section 2.9 shows how this is calculated).

The filler has zero cradle to gate CO_2e and zero transport CO_2e (see Section 2.5.1.7).

The bitumen has the following cradle to gate CO_2e: 150 $kgCO_2e/t$ (see Appendix D).

The associated transport CO_2e is 228.3 $kgCO_2e$ /20t (payload) = 11.4 $kgCO_2e/t$ (based on example in Section 2.9, with distance travelled equal to 100 vkm x 2 = 200 vkm).

The delivered constituent CO_2e in a metric tonne of this mixture is calculated as follows:

Constituents cradle to gate CO_2e:

(((785 + 150) x (1+5%) [kg]) x 2.06 [$kgCO_2e/t$]) + (15 [kg] x 0 [$kgCO_2e/t$]) + (50 [kg] x 150 [$kgCO_2e/t$]))/1000 [kg]

= 9.5 $kgCO_2e/t$

Constituents transport CO_2e:

(((785 + 150) x (1+5%) [kg]) x 3.50 [$kgCO_2e/t$]) + (15 [kg] x 0 [$kgCO_2e/t$]) + (50 [kg] x 11.4 [kgCO2e/t]))/1000 [kg]

= 4.0 $kgCO_2e/t$

As delivered CO_2e = 9.5 + 4.0 = 13.5 $kgCO_2e/t$

2.5 Constituent materials

The following asphalt component materials are included in this step:

- *Coarse aggregate*
- *Fine aggregate*
- *Reclaimed asphalt*
- *Manufactured aggregates*
- *Filler*
- *Bitumen*
- *Natural bitumen*
- *Fluxes*
- *Polymer-modified bitumen*
- *Bitumen emulsions*
- *Polymer-modified emulsions*
- *Synthetic binders*
- *Hydraulic binders*
- *Cement*
- *Hydrated lime*
- *Fibres*
- *Waxes*
- *Adhesion agents*
- *Pigments*
- *Water*
- *Others*

For each constituent material, the cradle to gate CO_2e per tonne at the source shall be determined in accordance with the requirements of this section.

For reclaimed asphalt planings there is an adjustment in the calculation of CO_2e in accordance with the approach adopted in this protocol to deal proportionately for future recyclability.

The CO_2e per tonne involved in transporting each constituent material to the asphalt plant shall be calculated separately in accordance with Section 2.9.

The sum of these two shall be taken as the delivered CO_2e for the constituent.

2.5.1 Aggregates

2.5.1.1 Primary aggregates

For the purpose of this protocol, a single figure for cradle to gate CO_2e shall be derived for each source based on the figures from the previous calendar year. The data for aggregates is obtained as a ratio of total CO_2e from all activities involved in the winning and processing of aggregates divided by the saleable tonnage [weighbridge tonnage adjusted for stock increase/reduction] produced at the production unit in the previous year. This shall include:

- *All electricity used on the site for aggregates production, excluding filler grinding and milling and any other downstream processes, in the previous year, converted to CO_2e as detailed in Appendix A.*
- *All fuel used on the site in the previous year, excluding for plants undertaking filler grinding and milling and any other downstream processes, converted to CO_2e as detailed in Appendix B.*

- *All explosive used by type per year multiplied by the cradle to gate CO_2e of manufacture and the CO_2e released on detonation in accordance with Appendix C.*
- *All mains water used per year multiplied by the CO_2e factor for supplying water which is provided in Appendix D.*
- *CO_2e emissions from overburden removal and restoration processes annualised over the anticipated period of use of the quarry face or sand and gravel pit.*

2.5.1.2 Crushed rock (quarry) and sand and gravel – land won

Include annual use of energy, per type of fuel/energy, electricity generated on site (renewable or otherwise) and that which is used on a green tariff[4], for both fixed plant (including offices and workshops) and loose plant (mobile crushers and screeners, drills, breakers, excavators, bulldozers, loaders, dump trucks etc.) used within a quarry/pit for overburden removal, primary extraction, further processing and screening through to restoration and loading for sale.

2.5.1.3 Sand and gravel – marine won

Include:

- *Annual fuel consumption of the dredgers used in extracting from the sea bed and discharging at wharf. The fuel consumption of a given dredger should be apportioned between the different wharves that it supplies throughout the year. This is calculated by dividing annual fuel consumption by the total tonnage dredged in the year and multiplying by the tonnage supplied to the wharf.*
- *Processing energy at the wharf by type of fuel/energy including electricity generated on site and green tariff[4] for all operation of fixed and loose plant.*

2.5.1.4 Crushed rock / sand and gravel – land won offshore

Include:

- *Energy use at the quarry/pit in accordance with Section 2.5.1.2 for land won material.*
- *Fuel consumption of the ships used to transport the material from the offshore source to the wharf shall be included. This transport shall be accounted for in accordance with Section 2.9.2.*
- *Processing energy at the wharf by type of fuel/energy including electricity generated on site and green tariff[4] for all operation of fixed and loose plant.*

2.5.1.5 Recycled aggregates and reclaimed asphalt planings (RAP)

Recycled aggregates and recycled asphalt planings are awarded zero CO_2e emissions at the first facility where they are deposited after excavation from the previous source.

All energy consumed thereafter in processing and transporting the recycled aggregate shall be accounted for and converted to CO_2e/t. This figure is referred to as 'proRAP' when used for recycled asphalt planings in Equation 4.

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[4] Electricity which is purchased on a green tariff and renewable energy consumption should be dealt with in a particular way according to Defra guidelines. The correct methodology to use is specified in Appendix A.

Include annual processing energy apportioned per tonne at depot per type of fuel/energy including electricity generated on site and that which is purchased on a green tariff[4] for all operation of fixed and loose plant.

2.5.1.6 Manufactured aggregates (e.g. glass, slag, ash)

Include annual processing energy apportioned per tonne at works per type of fuel/energy including electricity generated on site and that which is purchased on a green tariff[4] for all operation of fixed and loose plant, assuming zero CO_2e after the first tip from the industrial process generating the materials.

For instance:

- *Glass: zero CO_2e shall be assumed for waste glass tipped at the recycling site prior to reprocessing into aggregate;*
- *Slag: zero CO_2e shall be assumed for slag in the pit after tipping from the steel works prior to reprocessing into aggregate;*
- *Pulverised Fuel Ash (PFA): zero CO_2e shall be assumed for PFA as tipped from the precipitators of the power station for direct use as filler aggregate;*
- *Incinerator Bottom Ash (IBA): zero CO_2e shall be assumed for IBA from the bottom grates of the incinerators as tipped at the recycling site prior to reprocessing into aggregate.*

2.5.1.7 Filler

Where filler is produced as a primary product by milling or grinding primary aggregate, all of the energy used in this process shall be accounted for in the CO_2e calculation in addition to the CO_2e from the initial aggregate production.

Where filler is reclaimed in the asphalt plant or at the same location and used directly, it shall be awarded zero CO_2e.

Where filler is reclaimed in an asphalt plant or other dust arrestment facility and transported to another asphalt plant, only the CO_2e resulting from energy use in transporting the material shall be included.

2.5.2 Bituminous binders

2.5.2.1 Bitumen

A default cradle to gate CO_2e figure for bitumen is provided in the default data in Appendix D[5].

2.5.2.2 Polymer modified bitumen (PMB) types

A default cradle to gate CO_2e figure for PMB is provided in the default data in Appendix D. It is assumed that the polymer blending plant is located within the refinery. Any additional transport between the two locations must be accounted for in accordance with Section 2.9.

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[5] *The cradle to gate CO_2e of bitumen is calculated in the same way as for other materials. Any 'inherent' potential energy which would be released if bitumen were used for a fuel is not included as this is not derived from nor released in the life cycle of highways.*

2.5.2.3 Bitumen emulsions

Default cradle to gate CO_2e figures for bitumen emulsion and PMB emulsion are provided in the default data in Appendix D. It is assumed that the emulsion mill is located within the refinery. Any additional transport between the two locations must be accounted for in accordance with Section 2.9.

2.5.2.4 Natural bitumen

A default cradle to gate CO_2e figure for natural bitumen will be provided in the default data in Appendix D when an appropriate figure becomes available.

2.5.3 Cementitious materials

Default cradle to gate CO_2e figures for cementitious materials are provided in the default data in Appendix D.

2.5.4 Hydrated lime

A default cradle to gate CO_2e figure for hydrated lime is provided in the default data in Appendix D.

2.5.5 Other constituent materials

Default cradle to gate CO_2e figures are provided for fibres, waxes, adhesion agents, fluxes, pigments and water in Appendix D, where appropriate figures are available.

Exclusions

d. Grease, lubricating and hydraulic oils are outside the remit of this protocol.

Explanatory Notes – Constituent materials

For information about methods to convert energy and fuels into CO_2e, please consult the Explanatory Notes to Section 2.7.

Why is saleable [weighbridge] plus stock increase/reduction tonnage used?

Saleable tonnage which crosses the weighbridge plus stock increase/reduction, calculated according to the methodology applied to establish Aggregates Levy liability, represents useful product generated and is therefore the measure which should be used to apportion the life cycle impacts to determine the 'footprint' of a given quantity of product (1 tonne).

Why are overburden removal and restoration included?

The impacts of removal of overburden material before quarrying can commence and the impacts of restoration of the quarry after closure should be apportioned over every tonne of useful product generated from the area respectively cleared, or restored, otherwise the impacts of these activities will be unaccounted for. Restoration is based on a prediction of the restoration costs, mirroring the internal financial accounting system, and should be accounted for using relevant CO_2e data over the aggregate tonnage produced during the lifetime of the deposit. Quarry restoration (often with a higher level of vegetation that preceded it) precludes the need to consider any climate change impacts of land use changes during the lifetime of a quarry.

Why is the energy for grinding and milling excluded in calculating the cradle to gate GHG emissions of primary aggregates?

Additional processing undertaken by an aggregate production unit over and above the basic function of producing graded aggregate (e.g. grinding, milling, drying and production of industrial minerals) is deemed to be separate from primary aggregate production. These activities will be included within the GHG emissions calculation of other aggregate products (e.g. milled fines for filler) and should therefore be excluded from the calculation for primary aggregates.

Why are secondary, manufactured and recycled materials awarded zero emissions at the point where they are generated or first stockpiled?

The energy consumed in producing the waste which is then deemed secondary and recycled material (with or without further processing) in the asphalt life cycle is accounted for in other product lifetimes. It is therefore awarded zero emissions when it is first used in the asphalt life cycle. Any further processing to transform the waste into recycled/manufactured aggregates is included.

Why are GHG emissions from the disturbance of marine sediments in dredging not included in the calculation?

Research to date (Shively, 2003) has suggested that disturbance of marine sediments by dredging does not generate significant quantities of GHG emissions. This source of emissions is therefore excluded from calculations.

Explanatory Notes – Constituent materials (continued)

Have non-CO_2 GHGs associated with the production of constituent materials been considered?

Yes. Non-CO_2 GHGs which arise when some of the constituent materials are produced are included where data was available. See the data listed in Appendix D and the quality assessment in Appendix F for further information on the characteristics of the data sources selected.

Why are consumables including grease, lubricating and hydraulic oils outside the system boundary?

The material contribution of these materials to the life cycle GHG emissions of the product are anticipated to be significantly less than the 1% cut-off which is recommended by the specification. The threshold of materiality for petroleum based lubricants has been calculated as in excess of 3 L of lubricant per tonne of asphalt. If this threshold were exceeded then consumables should be included in the assessment, however, for this version of the protocol we are assuming that the threshold is not exceeded until further evidence can be collected which indicates otherwise.

Section 3.31 of the PAS states the materiality threshold of 1%.

Why is default data provided for the cradle to gate CO_2e content of constituent materials other than aggregates and filler?

In this initial version of the protocol, the use of non-specific default data was necessary due to the complexity of calculation that would be needed to generate primary data for all components. In later versions of the protocol it is hoped to include methods to determine primary data for these materials where suitable, practicable methods can be established. In using primary data for aggregates (primary, secondary and recycled) and filler a significant proportion of the asphalt mix (>90%) is covered by primary data. The use of default data (otherwise known as secondary data) is justified by PAS 2050, provided that the sources are suitably referenced.

Section 7.4 of the PAS discusses the use of secondary data.

Which process steps do the default data include?

The default CO_2e figures include all processes from extraction of raw materials through to the point where they can be used in the asphalt mix, not including transport to the asphalt plant which should be specified separately. In terms of the ten step representation in Figure 0.1, the first three steps would be considered in generating default data, producing a 'cradle to gate' analysis for these constituents.

Explanatory Notes – Constituent materials (continued)

Bitumen, as a crude oil fraction, has an inherent potential energy which can be released on combustion. Is this reflected in bitumen's cradle to gate CO_2e value?

No. Bitumen is treated in the same way as all other constituent materials. Embodied energy reflects the energy expended in sourcing, transporting and processing bitumen to the point where it is ready to be utilised in an asphalt mix. The inherent potential energy of bitumen is not released by combustion during the highway life cycle and is therefore not included in the CO_2e assessment. Should this framework be extended to consider resource depletion as an impact, in addition to contribution to climate change, then this depletion of energy bearing resources would become a relevant consideration. Stripple (2001) provides wider discussion on the inherent energy content of bitumen and its implications for impact assessment studies.

Worked Example – Overburden Removal

These worked examples use fictitious quantities for the purpose of illustration only.

At Quarry X, some 3,000 t of overburden requires removal to access 100,000 t of useful material, which will be extracted over 5 years. The overburden is removed using earth moving machinery and other equipment which consume 10,000 L of diesel. This fuel usage should be distributed over the 5 years of exploitation, i.e.

10,000 L / 5 yrs = 2000 L of diesel per year

shall be accounted for as yearly fuel use contribution for overburden removal. Similarly, it can be distributed over each tonne of material extracted:

10,000 L / 100,000 t = 0.1 L of diesel per tonne extracted

Worked Example - Restoration

Restoration impacts should be attributed to each tonne of aggregate produced using the predicted total mass of extraction at the quarry, which will be available on the extraction licence which has been granted. Average fuel use from past restoration activities (ideally of a similar scale), obtained from company accounts, shall be used.

For example, Quarry X, which is currently supplying aggregate to an asphalt plant, has planning permission to produce 100,000 t of useful material. In the past Quarry Y produced 100,000 tonnes and spent a total of £6300 on diesel used in plant for restoration in 2007.

In 2007 the price of red diesel was on average £0.42 per L (Defra Economics & Statistics, 2008), hence, at Quarry Y:

£6300 / £0.42 = 15,000 L of fuel consumed in restoration

And:

15,000 L / 100,000 t = 0.15 L of diesel per t extracted

Therefore 0.15 L of diesel should be attributed to each tonne of useful material produced at Quarry X to account for fuel use in restoration.

In total, 0.25 L of diesel use should be attributed to each tonne of useful material produced at Quarry X to take account of overburden removal and restoration. Fuels used other than diesel should be considered in the same way.

Fuel consumption data might be estimated, e.g. from industry experience, until actual information is available. Adjustments to forecasts shall be made with correction factors when actual data becomes available.

2.6 Reflecting the balance of recycled content and future recyclability in the mixture

The approach to recycling and recyclability adopted in asPECT is to set a balance between taking the carbon benefits of current recycling and of future recyclability in a 75:25 ratio. This recognises that asphalt (in comparison with other materials) has a very high future recyclability potential as it can be fully recycled as asphalt, but at the same time gives a bigger incentive to maximise current recycling.

$$\boldsymbol{constCO_2e = ((0.75 \times mixCO_2e) + (0.25 \times futCO_2e))\ kgCO_2e/t}$$

Equation 2

$mixCO_2e$ = embodied carbon of current mix constituents, taking into account recycled content, and calculated in accordance with Sections 2.4 and 2.5

$futCO_2e$ = embodied carbon of mix constituents, taking into account their potential to be recycled into future asphalt mixtures, and calculated in accordance with Section 2.6.1

2.6.1 Calculating future recyclability

The future recyclability of the asphalt mixture is reflected in a recoverability rate and also how much the recovered RAP will need to be supplemented with virgin material in its next life. This allows its benefit to the next mixture to be reflected in terms of CO_2e ($futCO_2e$):

$$\boldsymbol{futCO_2e = vmixCO_2e - \Big(R \times \big((b_M \times 150) + ((100\% - b_M) \times 4.93 \times 1.05) - futproRAP\big)\Big)\ kgCO_2e/t}$$

R = recoverability rate

$vmixCO_2e$ = embodied carbon of mix constituents, with no recycled content and calculated in accordance with Equation 4

b_M = virgin binder content of current mix (% m/m)

futproRAP =future CO_2e content of RAP per tonne

The recoverability rate (R) reflects the total loss of mass over the lifetime of the asphalt in wearing, extraction and subsequent processing to enable its further use. R is fixed at 95% for the purpose of calculations using asPECT[6]. futproRAP can also only be predicted at this time and is set at 1.009 $kgCO_2e/t$[7]. The factor of 1.05 is applied to reflect loss of virgin aggregate due to moisture and wastage (see Section 2.4).

[6] The recoverability rate (R) is the best estimate, based on industry consensus. This figure may be revised in future versions of asPECT should reliable evidence sources become available.
[7] The future CO_2e content of processed RAP (futproRAP) is set at 1.009 $kgCO_2e/t$. This is the content that is specified for recycled asphalt in BEIS's Greenhouse gas reporting: conversion factors[8]. It is anticipated that recycled aggregates and RAP will undergo a similar level of reprocessing.

Thus Equation 3 is:

$$\boldsymbol{futCO_2e} = \boldsymbol{vmixCO_2e} - \left(\mathbf{95\%} \times \left((\boldsymbol{b_M} \times \mathbf{150}) + \left((\mathbf{100\%} - \boldsymbol{b_M}) \times \mathbf{4.93} \times \mathbf{1.05}\right) - \mathbf{1.009}\right)\right) \boldsymbol{kgCO_2e}/\boldsymbol{t}$$

Equation 3

The CO_2e content of a virgin mixture ($vmixCO_2e$) must be calculated to enable the benefits of recycling to be realised. This can be done by calculating $mixCO_2e$ after substituting any recycled content for virgin binder and aggregate using Equation 4.

$$\boldsymbol{vmixCO_2e} = \boldsymbol{mixCO_2e} - (\boldsymbol{proRAP} \times \%\boldsymbol{RAP}) + \%\boldsymbol{RAP}\left(\left(\boldsymbol{Aggmix} \times \mathbf{1.05} \times (\mathbf{100\%} - [\boldsymbol{\gamma} \times \boldsymbol{b_R}])\right) + (\boldsymbol{Bitmix} \times [\boldsymbol{\gamma} \times \boldsymbol{b_R}])\right)$$

Equation 4

%RAP = percentage RAP included

Aggmix = weighted average of virgin aggregate embodied CO_2e values used in the mix

Bitmix = embodied CO_2e value of binder used in the mix

b_R = soluble binder content of RAP

γ = active binder content of RAP

Worked Example – Recycled content and recyclability

In this example, the 75:25 approach is used to calculate the benefits in terms of GHG emissions associated with the production of a 25% RAP content mixture. Please note that only theoretical mix recipes are used.

A simplified mix recipe for an 'all virgin materials' asphalt is as follows:

- Coarse & fine aggregates: 935 kg = 93.5%
- Filler: 15 kg = 1.5%
- Bitumen: 49 kg = 4.9%
- Crude derived wax: 1 kg = 0.1%

The following CO_2e emissions associated with the production of the virgin constituent materials are used:

	Production $kgCO_2e/t$
Virgin aggregates	4.93
Filler	0
Bitumen	150
Crude-derived wax	370

The CO_2e emissions associated with the constituents of the 'all virgin materials' asphalt mixture ($vmixCO_2e$) are calculated as follows:

$$= (((1+5\%) \times 935\ [kg] \times 4.93\ [kgCO_2e/t]) + (15\ [kg] \times 0\ kgCO_2e/t) + (49\ [kg] \times 150\ [kgCO_2e/t]) + (1\ [kg] \times 370\ [kgCO_2e]))/1000$$

$$= 12.6\ kgCO_2e/t$$

The composition of an alternative '25% recycled' ($mixCO_2e$) asphalt is as follows:

- Recycled asphalt planings: 250 kg = 25% (soluble binder content = 4% m/m)
- Coarse & fine aggregates: 695 kg = 69.5%
- Filler: 15 kg = 1.5%
- Bitumen: 39 kg = 3.9%
- Crude derived wax: 1 kg = 0.1%

The embodied CO_2e of RAP (proRAP) is 3 $kgCO_2e/t$.

The CO_2e emissions associated with the constituents of the '25% recycled' asphalt mixture ($mixCO_2e$) are calculated as follows:

$$= ((250\ [kg] \times 3\ [kgCO_2e/t]) + ((1+5\%) \times 695\ [kg] \times 4.93\ [kgCO_2e/t]) + (15\ [kg] \times 0\ kgCO_2e/t) + (39\ [kg] \times 150\ [kgCO_2e/t]) + (1\ [kg] \times 370\ [kgCO_2e]))/1000)$$

$$= 10.6\ kgCO_2e/t$$

In order to calculate the future recyclability, Equation 3 is used:

$$\mathrm{futCO_2e} = \mathrm{vmixCO_2e} - \left(95\% \times \left((3.9\% \times 150) + (96.1\% \times 4.93 \times 1.05) - 1.009\right)\right) \mathrm{kgCO_2e/t}$$

The calculation is performed as follows:

$$= \mathrm{futCO_2e} = 12.6 - \left(95\% \times \left(\left((3.9\% \times 150) + (96.1\% \times 4.93 \times 1.05)\right) - 1.009\right)\right) [\mathrm{kgCO_2e/t}]$$

= 3.2 $kgCO_2e/t$

Finally, apply Equation 2 to calculate the overall constituent CO_2e for the mixture:

$$= \mathrm{CO_2e\ (asphalt\ mixture)} = \left((0.75 \times 10.6) + (0.25 \times 3.2) \right) \mathrm{kgCO_2e/t}$$

= 8.7 $kgCO_2e/t$

The total benefit attributed to recycled content and the recyclability of asphalt in this example is 12.6 – 8.7 = 3.8 $kgCO_2e/t$ (to one decimal point).

Explanatory Notes – Credit from recycling

How is the recycling benefit derived?

The approach distributes the benefits of recycling between the users of recycled asphalt and the producers of recyclable asphalt. This share has been fixed at 75% for the users and 25% for the producers. This rewards users of RAP and it provides an incentive for the industry to increase the use of asphalt recycling. At the same time, this approach rewards those manufacturers who preserve recyclable asphalt, thus contributing to keeping open the future usability of asphalt back into asphalt.

Why has a 75:25 share between users and producers been chosen?

Currently, the amount of reclaimed asphalt actually recycled back into asphalt varies, depending on the client and specifications. A lot of recyclable asphalt might be used in lower grade applications. Fixing a higher share of benefits for the users of RAP is an incentive to ensure RAP is used into the application that provides the highest technical and environmental benefits, i.e. back into asphalt, and to encourage the addition of the largest possible percentage of RAP in a given mixture. On the other hand, there is still a need to recognise the potential future recyclability of asphalt and to reward manufacturers of asphalt mixtures that will be available for recycling in the future.

Why 75:25 not 50:50?

A 75% reduction in embodied CO_2e is applied to actual use of RAP in mixtures and a 25% reduction potential is applied to recognise the future recyclability of RAP. This ratio is chosen in recognition of the fact that closed-loop recycling of RAP to bound courses is currently relatively low, although levels are gradually increasing in relation to open-loop recycling to unbound courses. Therefore, at present, more reward is given to the actual practice of recycling than the future recycling potential. Materials with higher levels of recycling achieved as the norm would tend towards 50:50 ratios or even higher recyclability 'potentials'.

Why has this approach been chosen?

In life cycle assessment, the allocation of the 'environmental credits' (or benefits) derived from recycling depends on the aim and scope of the assessment. There is not a single universal approach, but a number of different methodologies. Two of the many were specifically taken into account.

PAS 2050:2011 presents two options. The first is a 'recycled content' approach that allocates all the environmental credits to the users of the recycled material, on the basis that the benefits of recycling can only be realised when the recycled material is used. The second approach, called the 'substitution method', allocates all the benefits to the producers of the material that can be recycled, on the basis that recyclable material would not exist without the system producing it in the first place. A combined approach is postulated as an alternative in Annex D.5 of the PAS, to be used in association with 'supplementary requirements', as have been devised for the highways sector in the creation of asPECT.

Explanatory Notes – Credit from recycling (continued)

Both the recycled content and substitution methods have merits and drawbacks and are applicable to asphalt as recyclable material which provides the highest benefits when recycled back into asphalt. It was felt that an approach combining the two methodologies would provide the best solution to quantify the environmental credits, shared between the users of recycled asphalt and the producers of recyclable asphalt.

A good discussion of recycled content and recyclability approaches and the intermediate solution is provided in Jones (2009).

2.7 Processing energy and water use at the asphalt plant

For the purposes of this protocol a single figure for process CO_2e per tonne shall be derived for each plant based on the data from the previous calendar year. This is the ratio of total CO_2e arising from all activities involved in mechanical processing divided by the sales tonnage [based on weighbridge records] produced at the asphalt plant in the previous year. This shall include:

- *All electricity used on the site in the previous year converted to CO_2e as detailed in Appendix A.*
- *All fuel used on the site in the previous year, excluding that used in heating and drying, converted to CO_2e as detailed in Appendix B.*

Include annual energy consumption of loose plant (e.g. loaders, shovels etc.) and fixed plant, excluding burner, per type of fuel/energy, including refuse derived fuel, on-site generated electricity and electricity consumed on a green tariff[4].

Additionally, all mains water used per year, multiplied by the CO_2e factor for supplying water which is provided in Appendix D, shall be accounted for.

Explanatory Notes – Processing energy

Why does energy consumption have to be split by fuel?

It is necessary for all energy used to be reported by type (e.g. electricity, gas, refuse derived oil etc.) to assign the correct emission factors in order to calculate CO_2e. The accompanying calculation tool uses the latest *Greenhouse gas reporting: conversion factors* (BEIS, 2019).

Why is last year's energy consumption data used?

Use of last year's data provides a full year of energy consumption figures on which to base the calculation of energy consumption per tonne of aggregate produced. This is based on the assumption that the energy consumption at a given quarry, used to produce a tonne of aggregate, does not vary significantly from one year to the next.

How is green tariff electricity accounted for?

Using Defra's recommendations, green tariff electricity has no special treatment since 'green' methods of electricity generation for the National Grid are already accounted for in BEIS's single emission factor for electricity; there is no separate figure for green tariff electricity. This, however, may be accounted for in future revisions of the protocol if some green tariffs exceed the renewable electricity energy obligations which are imposed on electricity suppliers by law.

How should on-site production of renewable electricity be accounted for?

Using Defra's recommendations, if renewable electricity is generated on-site and is not 'sold on' through Renewable Obligation Certificates (ROCs) or Levy Exemption Certifications (LECs) to a third party, this electricity should be rated as zero emission. If ROCs or LECs are sold, then the emission factor for electricity should be used. This avoids double counting the benefits of renewable generation.

What about non-CO_2 contributions of fuel use to climate change?

Non-CO2 gases are included in fuel use emissions factors by virtue of using the 'CO_2e' emissions factors available in the most current version of BEIS's *Greenhouse gas reporting: conversion factors* (BEIS, 2019)[8].

2.8 *Heating and drying energy at asphalt plant*

For the purposes of this protocol, data for the heating and drying CO_2e per tonne shall be calculated for each of a number of defined sub-groups of mixture types with similar heating/drying characteristics. The calculation of the basic group data and those for variants shall be in accordance with this section.

Every year an audit shall be undertaken to ensure that the total calculated for the estimate is equal to the actual consumption of the plant. If discrepancies are found, a correction factor shall be applied.

The following methodologies and principles shall be applied for each type of fuel used for heating and drying for the purpose of objectively apportioning the CO_2e to all products. The total GHG emissions shall then be calculated by summation of the GHG emissions associated with each fuel, in accordance with Appendix B.

2.8.1 Basic methodology (continuous single dryer)

The energy involved in heating and drying will be different for different mix types. Low fines content mixtures with low moisture content and low temperature mixes will consume less energy per tonne and generate less GHGs per tonne than high fines, high moisture and high temperature mixes. This protocol enables the CO_2e for a plant (continuous single dryer) to be allocated to different mix types based on knowledge of the plant operating characteristics.

It requires knowledge of the following:

- *Total production in the previous year.*
- *Total heating fuel consumption, per type of fuel, in the previous year.*
- *Tonnage produced of each of n mix types, grouped by fuel consumption. In the example, we consider mix types A, B, C, D, E, ...X.*
- *Production rate in tonnes per hour (tph) of each mix type at full burner setting.*
- *Notional production rate in tph of each mix type for special mix types calculated as in Section 2.8.3 'special processes' below.*

The formula below works on the basis that the fuel consumption per tonne of the mix groups will be in inverse proportion to their (maximum) production rates with the burner operating at maximum.

Mix production for a given F_{tot} annual energy consumption, per type of fuel (burner only):

Mix type	*Yearly production, t*	*Production rate, tph*
Mix 1	*T1*	*k1*
Mix 2	*T2*	*k2*
Mix 3	*T3*	*k3*
Mix 4	*T4*	*k4*
Mix 5	*T5*	*k5*
…	*…*	*…*
Mix X	*TX*	*KX*

The mix with the highest production rate K shall be identified and the energy F, per type of fuel, used for the production of a tonne of it shall be calculated using the formula:

$$F = \frac{Ftot}{\sum_{n=1}^{N} \frac{Tn*K}{Kn}}$$

Equation 5

Where N is the number of mix types.

The energy (F_n) per tonne, per type of fuel, used for each of the mixes is inversely proportional to the rate of production and shall be calculated using the formula:

$$Fn = F \times \frac{K}{Kn}$$

Equation 6

An example is provided in Section 2.8.3 below.

2.8.2 Batch heater plant

For batch heater plants, the energy use is directly proportional to the dwelling time. Mix production for a given F_{tot} annual energy consumption, per type of fuel (batch heater only):

Mix type	*Yearly production, t*	*Heating time, s*
Mix 1	*T1*	*t1*
Mix 2	*T2*	*t2*
Mix 3	*T3*	*t3*
Mix 4	*T4*	*t4*
Mix 5	*T5*	*t5*
…	*…*	*…*
Mix X	*TX*	*tX*

The mix with the longest heating time t shall be identified and the energy F, per type of fuel, used for the production of a tonne of it shall be calculated using the formula:

$$F = \frac{Ftot}{\sum_{n=1}^{N} \frac{Tn*tn}{t}}$$

Equation 7

Where N is the number of mix types.

The energy (F_n) used for a tonne of each of the mixes, per type of fuel, is proportional to the heating time and shall be calculated using the formula:

$$Fn = F \times \frac{tn}{t}$$

Equation 8

2.8.3 Special processes

It is necessary to calculate a notional production rate to feed into Equation 5 above for special processes and non-standard materials. This section specifies how the notional production rate shall be calculated.

Operating variants shall be considered by trial comparison with normal production in accordance with the procedures below:

- *Recycling – cold batch addition;*
- *Recycling - continuous addition;*
- *Parallel drum recycling pre-heater;*
- *Warm temperature mixing (additives/warm/foam).*

Continuous runs of both the non-standard process and one of the main standard production groups shall be monitored by measuring each type of fuel required to produce a minimum of 100 tonnes of each.

For special processes, the notional production rate k shall be calculated from the standard process rate as follows:

$$\boldsymbol{Notional\ k = standard\ process\ rate \times \left(\frac{standard\ product\ energy\ \left({}^{L}/_{t}\right)}{non - standard\ product\ energy\ \left({}^{L}/_{t}\right)} \right)}$$

Equation 9

Worked Example - Basic Methodology (continuous single dryer)

An example of the application of Equation 5, Equation 6 and Equation 9 using fictitious numbers, is given as follows:

Mix type	Yearly production, t	Production rate, tph	Consumption, L/t
Mix 1	100,000	100	F_1
Mix 2	200,000	200	F_2
Mix 3	150,000	150	F_3
Mix 4	50,000	50	15
Mix 5 (non-standard mix)	50,000	Notional rate k5	10

The total fuel consumption of the burner for the previous year was 3,500,000 L of fuel oil. No other fuel was used.

Mix 5 is a non-standard mix for which monitoring has been undertaken over 100 t of production. A tonne of mix 5 requires 10 litres of fuel per tonne. Mix 4 is being monitored for comparison; a tonne of mix 4 requires 15 litres of fuel per tonne.

The notional rate for mix 5 is calculated applying Equation 9 as follows:

Notional rate k5 = 50 tph x 15/10 = 75 tph

The mix with the highest production rate is Mix 2 (K = 200 tph) and the energy F used to produce a tonne of Mix 2 is as follows:

F = (3,500,000 L/200 tph) ÷ ((100,000/100) + (200,000/200) + (150,000/150) + (50,000/50) + (50,000/75)t/tph) = 3.75 L/t

The energy for producing a tonne of other mixes is as follows:

F1= 3.75 L/t x 200 tph/100 tph = 7.5 L/t

F2= F = 3.75 L/t

F3= 3.75 L/t x 200 tph/150 tph = 5 L/t

F4 and F5 are known from monitoring.

Explanatory Notes – Heating and drying energy

Have non-CO_2 GHG emissions arising at the asphalt plant been considered?

Yes, and they have been determined to be insignificant in terms of the asphalt life cycle. Stack emissions were considered to investigate whether any non-combustion GHGs above and beyond those determined by using emissions factors were arising. Inorganic emissions on an asphalt plant that arise from the stack are sulphur oxide (SO_2), mono-nitrogen oxides (NO_x), carbon monoxide (CO) and carbon dioxide (CO_2). Of these, CO and CO_2 are GHGs. NO_x is the term applied only to mono-nitrogen oxides and therefore does not include the GHG nitrous oxide (N_2O) (National Air Quality Archive, 2009). CO_2 is already accounted for in measuring the emissions associated with fuel use in accordance with Appendix B. CO is a short lived gas in the atmosphere due to its reactivity and is not considered to be in the basket of 6 significant GHGs (CO_2, methane (CH_4), nitrous oxide (N_2O), hydroflurocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6)).

What about other GHGs arising from refuse derived fuel (RDF)?

Chemical analyses of RDF indicate that non-CO_2 GHGs are not a major constituent of the combustion products of commonly used RDF (e.g. see below; Defra, 2004). Non-CO_2 GHGs are therefore not included in the analysis.

Sector	Factor kg/tonne	Emission in 2001 (tonnes)		% change
		2001 NAEI	2002 NAEI	
Carbon	865	256,000	275,000	+8%
Sulphur dioxide	11.4	892	3,630	+308%
Hydrogen chloride	0.195	NE	62.0	-
Cadmium	2.55×10^{-4}	0.205	0.0813	-92%
Chromium	1.49×10^{-3}	6.25	0.475	-60%
Copper	1.31×10^{-2}	4.14×10^{-2}	4.17	+100000%
Mercury	1.33×10^{-4}	3.18×10^{-5}	0.0423	+130000%
Manganese	2.14×10^{-3}	0.882	0.683	-23%
Nickel	1.75×10^{-3}	3.55	0.557	-84%
Lead	5.57×10^{-2}	6.37×10^{-2}	17.7	+28000%
Tin	1.20×10^{-3}	NE	0.382	-
Vanadium	3.06×10^{-3}	0.0159	0.975	+6000%
Zinc	0.853	4.14×10^{-2}	271	6600000%
Calcium	1.37	NE	435	-
Magnesium	0.140	NE	44.6	-
Potassium	5.64×10^{-2}	NE	18.0	-
Sodium	5.68×10^{-2}	NE	18.1	-

NE - not estimated

2.9 Transport

CO_2e emissions from transport shall be calculated in accordance with this section. The following activities are included:

- *Transport of constituent materials from source to asphalt plant.*
- *Transport of asphalt from asphalt plant to site.*
- *Transport of materials directly from factory to site.*
- *Transport of materials between factory sites where not elsewhere included in 'cradle-to-gate' figures.*
- *Transport of RAP from excavation site to first point of tipping.*

CO_2e emissions from transport shall be calculated using the 'activity plus well-to-tank' emissions factors available from the most current version of BEIS's Greenhouse gas reporting: conversion factors[8].

Information is required on the quantity of material transported, the utilisation level and the distance travelled, in km.

2.9.1 Road transport

The distance travelled shall include the return journey to the first point of loading, i.e. double the distance of the plant from the delivery site. The default assumption is for diesel use and the return journey empty (fleet utilisation; f = 50%). The following formula shall be applied to calculate the CO_2e emissions of the journey, using the most appropriate 'activity plus well-to-tank' emissions factors[8]:

$$\boldsymbol{kg\ CO_2e\ per\ journey} = \boldsymbol{Distance\ travelled}\ (\boldsymbol{vkm}) \times \left(\boldsymbol{Defra\ 50\%\ load\ factor}\ [\boldsymbol{Total\ GHG}\frac{[\boldsymbol{kgCO_{2e}}]}{[\boldsymbol{vkm}]}]\right) - \left((\boldsymbol{f} - \boldsymbol{50\%}) \times \boldsymbol{Defra\ 0\%\ load\ factor}\ [\boldsymbol{Total\ GHG}\frac{[\boldsymbol{kgCO_{2e}}]}{[\boldsymbol{vkm}]}]\right)$$

Equation 10

If vehicle utilisation differs from 50% (higher or lower), the utilisation factor (f) shall reflect the percentage of the total journey (outward bound and return) for which the vehicle is filled to its maximum payload and should be expressed as a percentage.

The percentage of hired haulage shall be used in the calculations, for which the utilisation factor (f) shall equal 50%.

[8] www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2019

Worked Examples - Transport

If a 32 t rigid truck travels a return journey totalling 60 vkm, with a full payload outward bound, empty on return (f = 50%), the following calculation shall be performed:

60 vkm x (1.166 $kgCO_2e$/vkm – ((50% - 50%) x 0.958 $kgCO_2e$/vkm))
= 69.96 $kgCO_2e$

If the truck had been more effectively utilised, carrying a full payload outward bound (20 t of 20 t available) and 6 t on return, (f) would be (26 t / 40 t x 100) = 65% and the calculation would have been:

60 vkm x (1.166 $kgCO_2e$/vkm – ((65% - 50%) x 0.958 $kgCO_2e$/vkm))
= 61.34 $kgCO_2e$

If the truck had been underutilised (f = 35%), this calculation would have been performed:

60 vkm x (1.166 $kgCO_2e$/vkm – ((35% - 50%) x 0.958 $kgCO_2e$/vkm))
= 78.58 $kgCO_2e$

If the proportion of hired haulage on the route was 30%, and company owned haulage was utilised at 65%, a combination of the top two calculated figures would be used, to provide average emissions for a vehicle on the route:

70% x 61.34 + 30% x 69.96 = 63.93 $kgCO_2e$

These calculated figures include direct emissions and indirect emissions (from pre-combustion processes), by virtue of using the 'activity plus well-to-tank' BEIS emissions factors[8].

2.9.2 Other transport (rail and water)

For rail, the distance travelled shall include the return journey. The total distance, from point of origin to the destination and return, shall be multiplied by the appropriate emissions factor. For mixed freight journeys (i.e. of quarry products and other goods) the 'activity plus well-to-tank' emissions factor available in the latest version of BEIS's Greenhouse gas reporting: conversion factors[8] shall be used. When quarry products are transported in isolation, an emissions factor specific to the Class 66 locomotive may be selected if appropriate (Strategic Rail Authority, 2001)[9].

For shipping, the distance travelled shall include the return journey, unless it can be justified that inclusion of only a single leg journey is necessary. The total distance, from point of origin to the destination (and return, unless otherwise justified) shall be multiplied by the most appropriate 'activity plus well-to-tank' emissions factor available in BEIS's Greenhouse gas reporting: conversion factors[8].

[9] *The Class 66 specific figure supplements the BEIS transport emissions factors and has been derived from a Strategic Rail Authority source. It is based on a 1500 t load and has been adjusted to include pre-combustion emissions. It is therefore directly comparable to the 'activity plus WTT' factors and should be applied at a rate of 0.1537 $kgCO_2e$/tkm.*

2.9.3 Transfer between transport steps

Fuel used to load and unload material from vehicles shall be included. Where not accounted for elsewhere, fuel use per tonne of material moved shall be measured and the appropriate 'activity plus well-to-tank' emissions factor applied from BEIS's Greenhouse gas reporting: conversion factors[8]*.*

Explanatory Notes - Transport

Has GHG generation in the life cycle of fuels up to the point of combustion been considered?

Yes. This acknowledges the fact that there are impacts incurred in the life cycle of fuels up to the point of combustion – the upstream impacts - associated with the provision of fuels (e.g. mining, transport and refining). These impacts were originally reflected as 'pre-combustion' emissions factors in v1.0 of asPECT. *BEIS's Greenhouse gas reporting: conversion factors* now reflect these impacts as 'well-to-tank (WTT)' emissions factors. We therefore recommend using the BEIS factors in place of the original pre-combustion factors in order to increase comparability across sectors. BEIS's 'activity plus WTT' emissions factors are now recommended for use throughout asPECT.

Section 6.4.3 of the PAS stipulates for the inclusion of emissions associated with the provision of energy sources.

What about non-CO_2 contributions of transport to climate change?

Non-CO_2 gases are included in fuel use emissions factors by virtue of using the 'CO_2e' emissions factors available in the most current version of BEIS's *Greenhouse gas reporting: conversion factors*[8].

How does the transport equation work?

The transport equation provides a method to realise the benefits of improved utilisation (or the drawbacks of underutilisation) in the emissions calculation for a single journey. It works on the principle that improved utilisation will avoid the requirement for another vehicle to undertake the same journey with part of the load. Similarly, for underutilisation, it takes account of the fact that another vehicle will have to undertake the same journey with part of the load. The equation is used to work out the balance of emissions which should be added or subtracted from the emissions of a single return journey with 50% utilisation, if the utilisation is changed. In an improved utilisation scenario, the 'balance' of emissions that is applied results from increasing the load factor but more so by avoiding some of the emissions from another vehicle's journey.

2.10 Installation at the construction site

2.10.1 Inclusions

CO_2e emissions which correspond to laying, compacting and related activities at the construction site shall be included as follows:

- *At a standard rate of 4.7 kgCO_2e per tonne of asphalt laid to reflect the fuel used in these processes or at a rate calculated in accordance with Section 2.10.2.*

2.10.2 Specific installation calculations

As an alternative to the standard rate of 4.7 kgCO_2e per tonne, the CO_2e per tonne for laying and compacting and related activities can be derived from first principles and should consider:

- *On-site fuel consumption of plant.*
- *Mobilisation of plant to site.*
- *Mobilisation of labour to site and on site.*

Calculations can used to arrive at a CO_2e figure per tonne for laying, compacting and related activities for:

- *A single job, in which case the calculations shall be based on the total fuel consumption for those activities across the job; or*
- *A company average figure, in which case the calculations shall be based on fuel consumption data for at least 5 different jobs, on which at least 30 full shifts of work installing asphalt have been carried out. Company average calculations should be repeated bi-annually.*

The following steps shall be undertaken to conduct the necessary calculations:

1. *Decide on the scope of the study (single job or company average) and identify shifts for which fuel consumption data will need to be taken into consideration, to make up the required sample as outlined above.*
2. *For the shifts identified in (1), record fuel consumption data from the bowsers used on site which are used to fuel the following plant (as a minimum):*
    - *Pavers*
    - *Rollers*
    - *Backhoe loaders*
    - *Tack sprayers/tankers*
    - *Fuel bowsers*
    - *Water bowsers*
    - *Electricity generators*
    - *Any additional energy generators*

3. *Fuel consumption should also be recorded for journeys made in mobilising plant and staff for the same shifts identified in (1). Journeys made by the following vehicles should be included (as a minimum):*
    - *Low loaders*
    - *Crew buses*
    - *Crew cars*
4. *The total tonnage of asphalt laid as a result of the shifts identified in (1) should also be recorded.*

The data collected should be used to arrive at a CO_2e per tonne figure for laying, compacting and related activities as follows:

5. *Calculate the total fuel consumption across all shifts by adding the total plant consumption data collected in (2) to the total transport consumption data collected in (3) to arrive at a total for each fuel type used.*
6. *Convert these fuel consumptions to CO_2e figures using BEIS's Greenhouse gas reporting: conversion factors[8] as outlined in Appendix B.*
7. *Divide this by the total tonnage laid to arrive at the CO_2e per tonne figure.*
8. *Retain all data for any independent verification which you may decide to pursue in the future.*

Explanatory Notes – Installation

How and why was a standard figure devised?

Installation represents a complex stage in the life cycle of asphalt, in terms of number of processes used, which equates to relatively little energy use (and therefore CO_2e generation). Some initial analyses by manufacturers (unpublished data) have found this energy use to be in the region of 5% or less of the overall amount used in the first seven steps of the asphalt life cycle. For these reasons a standard figure is provided.

The standard figure resulted from a working group in which six contracting companies were represented (Aggregate Industries, Cemex, Colas, Lafarge, Ringway and Tarmac). The figure was arrived at by taking the average of a number of measurements of fuel consumption on site by three companies. Fuel consumption was measured from on-site fuel bowsers and equated to the amount of material laid. Site mobilisation was also quantified and included in the figure.

The methodology followed to arrive at the standard figure has been standardised, and is presented in Steps 1 to 8 above, in case individual site contractors or asphalt manufacturers wish to repeat the exercise and calculate their own figure for CO_2e emissions for installation to apply to their own jobs.

2.11 Materials direct to site

Materials transported directly to site such as aggregates, geosynthetics and tack/bond coat can be accounted for in the calculation. The CO_2e values of any materials used should reflect cradle-to-gate and installation processes, and transport accounted for in accordance with Section 2.9. The CO_2e impacts of these materials can be included in 'project' calculations but not in the CO_2e figures for individual asphalt products.

2.12 Product lifetime

In producing a life cycle carbon assessment, the service lifetime of the product shall be considered from installation through to the point where the material is first planed off or bulk excavated from the road. This allows the durability of the material to be taken into account in the total CO_2e assessment.

2.12.1 Aspirational design lifetimes

Aspirational design lifetimes[10] for asphalt materials should be selected from Table 2-1. If enhanced lifetimes are used which differ from these (e.g. if a modifier is used) then they should be justified with supporting evidence which has been submitted for approval.

The end point of the first life cycle of an asphalt product is deemed to be when the material is planed off or bulk excavated.

Table 2-1 Aspirational design lives for the principal asphalt types

		Design Lifetime	
Course	**Asphalt Material**	**Designed Road**	**Evolved Road**
Surface	Thin Surface Course Systems	15	10
	Paver Laid Surface Dressing	10	10
	Micro-surfacing	6	6
	Hot Rolled Asphalt (high stability)	20	20
	Hot Rolled Asphalt (low stability)	-	25
	Close Graded Macadam	8	6
	Surface Dressing (racked in)	10	12
	Surface Dressing (single)	6	10
Binder	Hot Rolled Asphalt	30	20
	Stone Mastic Asphalt	30	20
	Dense Bituminous Macadam / Heavy Duty Macadam	30	20
	Enrobés à Module Élevé (EME)	50[11]	20
Base	Dense Bituminous Macadam / Heavy Duty Macadam	40	-
	Enrobés à Module Élevé (EME)	50[11]	-

2.12.2 In situ maintenance

If a material is maintained in situ, without any major planing off or excavation, then the CO_2e of these treatments (materials, transport and processes) shall be included in the assessment. The treatments that shall be considered are as follows:

- *Overlay*
- *Surface dressing*

[10] Aspirational design lifetimes are reasonable life expectancies for asphalt materials that should be achieved in a correctly maintained pavement i.e. according to TRL Road Note 42 'Best Practice Guide for Durability of Asphalt Pavements'. If these lifetimes are not being achieved then the design should be re-visited.
[11] This figure is based on an estimate of future performance.

- *Slurry/micro surfacing*
- *Patching*
- *Crack sealing*
- *Retexturing*

The CO_2e/t for these treatments shall be obtained as follows:

- *If these materials are asphaltic, then the associated CO_2e per tonne shall be calculated in accordance with Sections 2.4 to 2.10 of this protocol, which cover Steps 1-7 of the asphalt life cycle.*
- *From the Road Surface Treatment Association (available from Spring 2011 onwards). The CO_2e per square metre for road surface treatments, calculated in accordance with Sections 2.4 to 2.10 of this protocol, will be made available.*
- *For materials that do not fit into the two categories above, the embodied CO_2e per tonne should be determined from the manufacturer or by using the default values available in Appendix D. To this the transport CO_2e per tonne should be added, calculated in accordance with Section 2.9.*

In all cases these treatments should be apportioned per tonne of the original asphalt laid, since they are applied to enhance the performance of this existing asphalt. It is then appropriate to specify an additional predicted lifetime due to these treatments in addition to the predicted design lifetime specified in accordance with Section 2.12.1, on the basis of supporting evidence.

2.13 Excavation

End of life is defined as the point where asphalt ceases to serve its original function in the road structure and is planed-off and moved to a stockpile or to a landfill site. This deposit is deemed to be the final point in the life cycle of asphalt. Taking planings from a stockpile in the future to serve another function constitutes the first step in another product life cycle.

Excavation is the logical end-of-life step for asphalt. However, when conducting a whole life CO_2e assessment for a given maintenance job it is necessary to evaluate the end of life step based on the destination of planings from the existing expired pavement. In this case the actual quantities of planings that are stockpiled and landfilled shall be used, as specified in contractual documents such as the bill of quantities or waste transfer notes.

2.13.1 Inclusions

The CO_2e contribution of the following activities within the excavation process shall be considered:

- *The planing activity, at a standard rate according to the width of planer and the depth of planing (available in Appendix I), or alternatively calculated in accordance with Section 2.13.2. Standard figures already include:*
  - *Mobilisation of planing equipment to site.*
  - *Mobilisation of labour to and on site.*
- *Transport of the excavated material to a stockpile or a landfill in accordance with Section 2.9.*
- *Emissions associated with the decomposition of the material that is sent to landfill, at a rate per tonne specified for 'aggregates' in the current set of BEIS's Greenhouse gas reporting: conversion factors[8,12].*

2.13.2 Specific excavation calculations

As an alternative to the standard rates of CO_2e production per tonne, which are available in Appendix I, the CO_2e per tonne for planing and related activities can be derived from first principles and should consider:

- *On-site fuel consumption of plant.*
- *Mobilisation of plant to site.*
- *Mobilisation of labour to site and on site.*

Calculations can used to arrive at a CO_2e figure per tonne for planing and related activities for:

- *A single job, in which case the calculations shall be based on the total fuel consumption for those activities across the job; or*
- *A company average figure, in which case the calculations shall be based on fuel consumption data for at least 5 different jobs, on which at least 30 full shifts of*

[12] The net rate per tonne specified in the emissions factors at the time of writing was 1.264 kgCO_2e per tonne of aggregate (RAP) landfilled.

work installing asphalt have been carried out, half in Summer and half in Winter. Company average calculations should be repeated bi-annually.

The following steps shall be undertaken to conduct the necessary calculations:

1. *Decide on the scope of the study (single job or company average) and identify shifts for which fuel consumption data will need to be taken into consideration, to make up the required sample as outlined above.*
2. *For the shifts identified in (1), record fuel consumption data from the bowsers used on site which are used to fuel the following plant (as a minimum):*
    - *Planers*
    - *Fuel bowsers*
    - *Electricity generators*
    - *Any additional energy generators*
3. *Fuel consumption should also be recorded for journeys made in mobilising plant and staff for the same shifts identified in (1). Journeys made by the following vehicles should be included (as a minimum):*
    - *Low loaders*
    - *Crew buses*
4. *The total tonnage of material planed-off as a result of the shifts identified in (1) should also be recorded.*

The data collected should be used to arrive at a CO_2e per tonne figure for planing and related activities as follows:

5. *Calculate the total fuel consumption across all shifts by adding the total plant consumption data collected in (2) to the total transport consumption data collected in (3) to arrive at a total for each fuel type used.*
6. *Convert these fuel consumptions to CO_2e figures using BEIS's Greenhouse gas reporting: conversion factors[8] as outlined in Appendix B.*
7. *Divide this by the total tonnage planed-off to arrive at the CO_2e per tonne figure.*
8. *Retain all data for any independent verification which you may decide to pursue in the future.*

2.14 Whole life considerations

Assessments which extend beyond initial installation, to consider Steps 8-10 of the asphalt life cycle (covered by Sections 2.11 to 2.13), in addition to Steps 1-7, are termed 'whole life carbon assessments'. In order to compare products on a whole life basis, it is necessary to normalise the CO_2e impacts across the lifetime on a temporal basis. This shall be done by dividing the total CO_2e impacts calculated for the product in accordance with Sections 2.1 to 2.13 by the product lifetime determined in accordance with Section 2.11, as indicated in Equation 11. Thus different asphalt products can be compared on the basis of CO_2e/t/year.

$$\boldsymbol{Whole\ life\ carbon\ impact} = \frac{\boldsymbol{CO_2e\ impacts\ Steps\ 1-10\ (^{kgCO_2e}/_{t})}}{\boldsymbol{product\ lifetime\ (years)}}$$

Equation 11

Explanatory Notes – Life Cycle Considerations

What about impacts in the use phase?

Use phase impacts are not included for a number of reasons. The foremost reason is that use of road vehicles, not the road pavement itself creates emissions which contribute to climate change.

Why were 'design' lives used?

Design lives were thought to be the least ambiguous measure of product lifetime, as opposed to any other method which is dependent on circumstances.

How were the design lives arrived at?

The design lives were arrived at through an evaluation of a survey of Local Authority Highway Engineers conducted by CSS, the findings of TRL report 674 (Nicholls *et al*., 2010) and the expert opinion of the project's steering group. Submission of evidence relating to the design lifetimes of asphalt products, which can be considered in relation to future revisions of Table 2-1, is positively encouraged.

How are standard planing energies derived?

Planing energies were determined on the basis of a survey of theoretical machine performances from manufacturers. The mobilisation of equipment and crew components of the standard installation figure calculated for Section 2.10 were added to the planing energies at a rate of 1.0 $kgCO_2e$/t of asphalt planed.

Why is the destination of excavated material based on the current contract?

It is difficult to predict the final management route for the new asphalt material being laid, hence it is appropriate to use the destination of the excavated material instead. This ensures that landfilled material does not go unaccounted for.

Section 6.4.10 of the PAS deals with final disposal.

Appendix A Converting grid electricity consumption to CO_2e equivalents

To calculate emissions of carbon dioxide associated with use of electricity:

1. *Identify the amount electricity used, in units of kWh.*
2. *Identify the 'activity plus well-to-tank plus transmission and distribution losses' conversion factors for electricity use (country specific, where necessary), which can be found within the most current version of BEIS's Greenhouse gas reporting: conversion factors*[8]*.*
3. *Multiply the amount of electricity used by the emissions factor identified in (2) and adhere to the following:*
    a) *For renewable electricity generated on-site, which is not 'sold on' in the form of Renewable Obligation Certificates (ROCs) or Levy Exemption Certifications (LECs) to a third party, this electricity should be rated as zero emission. 'Renewable electricity' in this context should be considered any form of generation that does not emit carbon dioxide, or generation of electricity with renewable biomass.*
    b) *For renewable electricity generated on-site, which is sold on in the form of Renewable Obligation Certificates (ROCs) or Levy Exemption Certifications (LECs) to a third party, emissions should be calculated as per conventional electricity use.*
    c) *The use of green tariff electricity shall not correspond to use of a lower conversion factor for electricity.*

Appendix B Converting fuel consumption to CO_2e equivalents

To calculate emissions of carbon dioxide emissions associated with fuel use:

1. Identify the type of fuel used: fossil fuel (e.g. diesel, fuel oil, gas etc.), biofuel, refuse derived, other.

2. Identify the amount of fuel used.

3. Identify the units of energy consumption (mass, volume or energy) and make the appropriate conversion to mass, using the conversion factors provided in Appendix G.

4. Ensure that this is gross energy consumption (i.e. based on the energy content of the fuel before use).

With the information gathered, apply the following steps, based on the fuel type:

a) For fossil fuels (e.g. diesel, fuel oil, gas):

i. Identify the appropriate 'activity plus well-to-tank' conversion factor (net calorific value basis) within the most current version of BEIS's Greenhouse gas reporting: conversion factors[8], which matches the fuel and unit you are using. If you cannot find a factor for that unit, Appendix G gives guidance on converting between different units of mass, volume and energy.

ii. Multiply the amount of fuel used by the combined conversion factor to get total emissions (kgCO_2e).

b) For biofuels (e.g. biodiesel):

i. Ask your supplier to specify the type and percentage of the component derived from biomass (referred as '% biofuel' in the formula in Step (5)) and the type of fossil fuel making up the mixture.

ii. Find the 'activity plus well-to-tank' emissions factor for the fossil fuel as specified in the section above (EFfossil fuel).

iii. Find the appropriate 'activity plus well-to-tank' biofuel emissions factor in BEIS's Greenhouse gas reporting: conversion factors[8].

iv. Apply Equation 12:

$$\boldsymbol{Emissions\ factor\ for\ fuel\ (with\ a\ \%\ biofuel) = (\%\ biofuel \times EF_{biofuel}) + \big((1 - \%\ biofuel)) \times (EF_{fossil\ fuel})\big)}$$

Equation 12

v. Multiply the amount of fuel used by the calculated emissions factor to get total emissions (kgCO_2e).

c) For refuse derived oil and novel fuels, to calculate combustion emissions for fuels not listed within BEIS's Greenhouse gas reporting: conversion factors[8]:

i. Obtain the fuel composition from the supplier and apportion the conversion factors provided in BEIS's Greenhouse gas reporting: conversion factors[8], or obtain the net calorific value (energy per tonne, in multiples of J/t) and apply a generic factor of 20 kgCO_2e/GJ (UNEP, 2000).

ii. *Ensure that this includes an estimate of emissions released during pre-combustion processes.*

Bespoke CO_2e conversion factors which are generated and are not listed in BEIS's Greenhouse gas reporting: conversion factors[8] shall be submitted with supporting information to inform future versions of the protocol. Submissions can be made via sms@trl.co.uk.

Appendix C CO_2e resulting from the use of explosives

The following emission factors for blasting fumes from commonly used explosives have been obtained from the LCA of Aggregates commissioned by WRAP to MIRO and Imperial College London (unpublished data):

Emissions to atmosphere - Blasting fumes				
	from ANFO	from Emulsion	From Nitro	Units
CO_2	167.0	166.0	166.1	$kgCO_2$/tonne

Data are in $kgCO_2$ per tonne of explosive used.

No other GHG emission factors other than for CO_2 are available, hence it is assumed that the emissions calculated with above factors are representative of the total GHG emissions on explosion.

The cradle to gate energy associated with the production of explosives is also included within the default data available in Appendix D.

Appendix D Default cradle to gate CO_2e data for various constituents ex works[13] unless specified

The following secondary sources of data are provided for use where primary data is not available.

Constituent Material	***Cradle to gate CO_2e ($kgCO_2e/t$)***	***Data Source***
Adhesion Agents[13]	*1200*	*Industry average, 2009*
Bitumen[13]	*150*	*Eurobitume, 2020*
Bitumen Emulsion (residual bitumen)[13,14,15]	*180*	*Data collated by the Refined Bitumen Association*
Cement (Portland Cement CEM I)	*860*	*BCA, CSMA, UKQAA, 2019*
Explosives	*3900*	*Estimate from IPCC Emissions Factors, 2006*
Fibres	*0.20*	*Industry average, 2019*
Fluxes (kerosene based)[14]	*370*	*European Commission, 2009*
GGBS	*80*	*BCA, CSMA, UKQAA, 2019*
Hydrated Lime	*780*	*Hammond & Jones, 2020*
Natural Bitumen	*TBA*	*-*
PFA (as binder)	*0.1*	*BCA, CSMA,UKQAA, 2019*
Pigments	*TBA*	*-*
Polymer Modified Bitumen (PMB)	*340*	*Data collated by the Refined Bitumen Association*
Polymer Modified Bitumen Emulsion (residual bitumen)[13,14,15]	*300*	*Data collated by the Refined Bitumen Association*
Water	*0.34*	*BEIS, 2019*
Wax (Fischer-Tropsch synthetic wax)	*2010*	*Estimate from European Joint Research Centre data, 2008*
Wax (Crude derived paraffin wax)	*370*	*European Commission, 2009*

[13] With the exception of the bituminous constituents and adhesion agents, for which transport to the UK has already been included (but not onward transport from a UK depot), any transport of constituents beyond the factory gate, whether in the UK or overseas, should be assessed separately in accordance with Section 2.9 and included.

[14] The default cradle to gate CO_2e data for bitumen emulsion and polymer modified bitumen emulsion has been calculated for the residual bitumen independent of the binder content of the emulsion. The transport CO_2e data should allow for transport of the emulsion from the depot to the road construction site. The utilisation of these journeys should be adjusted to take account of the water content of the emulsion since only the residual bitumen is used in mixtures, e.g. if a 50% emulsion is transported to a location and then returns empty, the journey will only have an effective utilisation of 25% with respect to the residual bitumen which is included in the mix recipe.

[15] In calculating the default cradle-to-gate CO_2e figures for bitumen emulsions, polymer modified bitumen and polymer modified bitumen emulsions, it is assumed that the polymer blending plant and/or the emulsion mill are located within the refinery. Any transport between these sites must be accounted for separately.

Explanatory Notes – Default Data Values

Why are some values marked 'TBA'?

In this edition of the protocol, it has not been possible to determine appropriate datasets to inform all of these values. Data collection will be an on-going task and by the next edition of the document it is hoped that these gaps will be filled.

How is the default data selected or derived?

All default data has been approved for use by the project focus group. Where several data sources are available for one constituent the chosen source has been selected or estimated on the basis of the PAS 2050, data quality rules concerning geographical, temporal and technological applicability have been considered and the findings presented in Appendix D.

Data quality rules are presented in Section 7.2 of the PAS.

Are all default data PAS 2050 compliant?

It is possible that some of the data are not fully PAS compliant, since they were generated before the PAS was written and have not been updated since. However, PAS compliance was one of the considerations made when selecting the default data for use.

Appendix E Pre-combustion CO_2e factors for energy use

The original pre-combustion factors presented in this Appendix have now been removed. Since Version 1.0 of asPECT, Defra and BEIS have included 'Indirect GHG' emissions factors, as a component of 'activity plus well-to-tank' emissions factors, which reflects pre-combustion in a more standardised format.

Appendix F Data quality assessment

The PAS introduces a number of data quality rules to assess the suitability of data to use in an emissions assessment. These have been applied to the default data which are presented in Appendix C and Appendix D.

Section 7.2 of the PAS specifies the data quality rules which should be considered.

Data point(s) *(secondary data)*	***Source(s)***	***Calculation Notes, Accuracy***	***Temporal considerations***	***Geographical specificity***	***Technological applicability***
Industry averages on CO_2e contents	*Industry surveys by TRL, specific companies not listed to protect confidentiality.*	*Averages of collected data.*	*Sourced 2008-2020*	*Actual suppliers of UK asphalt companies.*	*Unknown*
Collated data on CO_2e contents of polymer modified bitumen emulsions	*Data collated by the RBA to protect the confidentiality of its members.*	*Averages of collected data.*	*2011*	*Actual bitumen suppliers of UK asphalt companies*	*Representative of UK practices*
CO_2e contents of cementitious products	*BCA et al. published source.*	*Industry average selected by Steering Group.*	*2019*	*UK average*	*Representative of UK practices*
CO_2e content of bitumen, bitumen emulsion and polymer modified bitumen	*Eurobitume published source.*	*Single data point calculated from life cycle inventory.*	*2020*	*European representative*	*Representative of European practices*
CO_2e content of hydrated lime	*Hammond & Jones peer reviewed source.*	*Based on 39 records and an estimate of fuel mix.*	*Compiled in 2008*	*UK average*	*Representative of UK practices*
CO_2e contents of most fuels, crude derived wax & fluxes	*European Commission, platform on LCA (web-based).*	*CO_2, CH_4 and N_2O emissions to air taken from life cycle inventories.*	*2002-2003*	*EU-15*	*Complex refinery (producing all fractions) based in the EU*
CO_2e contents of LPG fuel	*Estimate from European Joint Research Centre data.*	*Well-to-wheels LCI of transport fuels.*	*2008*	*EU representative*	*Representative of European practices*

Data point(s) *(secondary data)*	***Source(s)***	***Calculation Notes, Accuracy***	***Temporal considerations***	***Geographical specificity***	***Technological applicability***
CO_2e contents of supplied water	*BEIS*	*Average based on individual company reporting.*	*2019*	*UK average*	*Based on all technologies utilised across the UK*
CO_2e contents of explosives	*Estimate from IPCC Emissions Factors, 2006.*	*Emissions factors of nitric acid, ammonia and fuel oil combined.*	*2006*	*Worldwide*	*Unknown*
CO_2e emissions from explosive detonation	*WRAP unpublished data.*	*Estimated from Australian GHG emissions factors.*	*2006*	*Worldwide*	*Typical explosives used in the industry*

Appendix G Converting between units of mass, volume and energy

The following table gives conversion factors to switch between various units of energy.

From/To - multiply by	GJ	kWh	therm	toe	kcal
Gigajoule, GJ	1	277.78	9.47817	0.02388	238,903
Kilowatthour, kWh	0.0036	1	0.03412	0.00009	860.05
Therm	0.10551	29.307	1	0.00252	25,206
Tonne oil equivalent, toe	41.868	11,630	396.83	1	10,002,389
Kilocalorie, kcal	0.000004186	0.0011627	0.000039674	0.000000100	1

Typical heat content of fuels.

Fuel properties	Net CV	Gross CV	Density	Density
	GJ/tonne	GJ/tonne	kg/m3	litres/tonne
Petrol	44.72	47.07	734.8	1361
Diesel	43.27	45.54	834.0	1199
Fuel Oil	41.46	43.64	986.2	1014
Kerosene	43.87	46.18	803.9	1244
Light Fuel Oil	43.27	45.54	865.8	1155
Natural Gas	47.59	52.82	0.7459	1340651
Coal	25.56	26.90	-	-
Naphtha	45.11	47.48	689.7	1450
LPG	46.98	49.45	508.1	1968
Wood Pellets	16.62	17.50	1538.5	650
Biodiesel (methylester)	37.20	41.04	890.0	1124
Biodiesel (HVO)	44.00	46.32	780.0	1282
Bioethanol	26.80	29.25	794.0	1259
BioETBE	36.30	39.62	750.0	1333

(Defra, 2014)

Appendix H Updates to asPECT

asPECT will be updated periodically by agreement between the endorsing bodies. The following will be considered:

- *Whether any of the stated rules, calculation methodologies or guidance need amending;*
- *Whether any of the default data or conversion factors need replacing, as new supporting evidence has arisen or been submitted for consideration since the last update;*
- *The scope of the documents in relation to industry practice and whether any sections should be added or removed to the documents to re-align them;*
- *The CO_2e claims of any novel fuels which have been submitted to the committee since the last update.*

The release of any new document versions will be communicated via the industry press and other suitable methods, and will be made available on the www.sustainabilityofhighways.org.uk website.

Appendix I Standard planing CO_2e contributions

The table below presents the standard planing CO_2e contributions to use in $kgCO_2e/t$ of asphalt excavated.

Planer width (m)	Planing depth (mm)																													
	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**	**130**	**140**	**150**	**160**	**170**	**180**	**190**	**200**	**210**	**220**	**230**	**240**	**250**	**260**	**270**	**280**	**290**	**300**
0.35	14.7	9.3	8.0	7.5	7.2	7.0	7.0	6.8	6.7	6.8																				
0.50	7.3	4.2	3.8	3.5	3.3	3.3	3.3	3.5	3.4	3.5	3.8	3.8	3.9	4.1	4.1	4.2														
1.00	7.5	4.2	3.2	2.8	2.7	2.5	2.5	2.5	2.5	2.4	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.6	2.8	2.8	2.8	2.8	2.8	2.8					
2.00	7.4	4.3	3.5	3.1	2.9	2.6	2.6	2.5	2.6	2.5	2.5	2.5	2.5	2.6	2.7	2.6	2.7	2.8	2.8	2.9	3.0	3.2	3.2	3.3	3.3	3.4	3.4	3.4	3.5	3.5
2.20	11.2	5.8	4.2	3.7	3.3	3.2	3.0	2.9	2.8	2.8	2.8	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.8	2.8	2.9	3.0	3.0	3.1	3.1	3.2

Appendix J Meeting principles for sector-specific supplementary requirements

PAS 2050:2011 Clause 4.3 principle	*asPECT justification*
*(a) **supplementary**: requirements and related guidance for which specific provision is made in this PAS and that are supplementary to and not in conflict with it.*	*An interpretation of PAS 2050 for the highways sector is the basis of asPECT – any additional requirements compliment this interpretation.*
*(b) **broadly recognized**: internationally, nationally, industry or sector wide.*	*The asPECT methodology is recognised by the key UK stakeholders: Highways Agency, Mineral Products Association, Refined Bitumen Association and ADEPT.*
*(c) **inclusive and consensus-based**: developed through a transparent process that is open to stakeholders.*	*asPECT was developed over a 3 year period, throughout which stakeholders were engaged and invited to contribute to the development process at any time. Feedback is still invited through the mailbox sms@trl.co.uk.*
*(d) **scoped appropriately**: having scope and requirements that are directly applicable to the specific stakeholder base.*	*asPECT is centred on asphalt and related road construction products; all of which are directly relevant to the stakeholder base.*
*(e) **harmonized**: developed after having regard to relevant existing product sector or category rules, guidance or requirements by adopting, referencing or building on these. Where there is a valid reason for them not being adopted, the reason shall be clearly justified and referenced within the supplementary requirements.*	*The Sustainability of Construction Works - Environmental Product Declarations - Core Rules for the Product Category of Construction Products, introduced in standard EN 15804 were released in 2012, after the first release of asPECT. In producing the current version of asPECT, no particular areas of conflict were found, given its particular scope.*
*(f) **comprehensive**: address all stages of the relevant product life cycle either by the inclusion of specific requirements where permitted by PAS 2050 or by deference to it.*	*asPECT's cradle-to-grave approach is comprehensive. Any omissions (e.g. in relation to the "use" phase) are fully justified.*
*(g) **justified**: by the inclusion of rationales identifying and explaining the supplements to the assessment method provided in PAS 2050 and confirming how the principles set out in a) through h) of this clause have been met;*	*The justification for the supplements is provided throughout this guidance document, in 'Explanatory Notes' boxes, and against the clauses (a) to (h) in this appendix.*
*(h) **publicly available**: free from use restrictions and in the public domain;*	*asPECT is free to obtain at www.sustainabilityofhighways.org.uk*

(i) ***maintained****: ensuring validity over time.*	*asPECT is maintained periodically – see Section 0 for specific details regarding the scope of this update.*

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Disclaimer

Whilst every effort has been made to adhere to the requirements of PAS 2050 in producing this document, TRL cannot guarantee conformance to the specification should the views of an independent auditor/verifier be sought to verify claims made using it.

References

British Cement Association (BCA), Cementitious Slag Makers Assocation (CSMA), UK Quality Ash Association (UKQAA) (2019) *Fact sheet 18 [update]: Embodied CO_2 of UK cement, additions and cementitious material. MPA: London.*

British Standards Institution (2008) *Specification for the assessment of the life cycle greenhouse gas emissions of goods and services (PAS 2050) [online].*
http://www.bsigroup.com/en/Standards-and-Publications/Industry-Sectors/Energy/PAS-2050/
[Last accessed: May 2011]

British Standards Institution (2011) *Specification for the assessment of the life cycle greenhouse gas emissions of goods and services (PAS 2050) [online].*
http://shop.bsigroup.com/en/forms/PASs/PAS-2050/
[Last accessed: December 2013]

BS EN ISO 14044:2006 *Environmental management – life cycle assessment – requirements and guidelines.*

Carbon Trust (2008) *Energy and carbon conversions [online].*
http://www.carbontrust.co.uk/publications/publicationdetail.htm?productid=CTL018
[Last accessed: June 2009]

Defra (2004) *Emission factors programme task 1 – summary of simple desk studies (2003/4), Section 3.18, Table 16 [online].*
http://www.airquality.co.uk/archive/reports/cat08/0407081213_SimpleStudies_Yr2_report_issue1.pdf
[Last accessed: May 2011]

Defra (2014) *Government Greenhouse Gas Conversion Factors for Company Reporting [online].*
http://www.ukconversionfactorscarbonsmart.co.uk/
[Last accessed: December 2014]

Defra Economics & Statistics (2008) *Agriculture in the UK 2008 - tables & charts, Chart 6.3 red diesel [online].*
http://archive.defra.gov.uk/evidence/statistics/foodfarm/general/auk/latest/excel/
[Last accessed: May 2011]

Department for Business, Energy and Industrial Strategy (2019) *BEIS's Greenhouse gas reporting: conversion factors [online].*
https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2019
[Last accessed: May 2020]

Eurobitume (2020) *Life cycle inventory: bitumen. Brussels: Belgium.*

European Commission (2009) *European life cycle data system (ELCD), v 1.0.1 Energy carriers. [online].*
http://lca.jrc.ec.europa.eu/lcainfohub/datasetCategories.vm?topCategory=Energy+carriers
[Last accessed: June 2009]

European Commission Joint Research Centre. Institute for Environment and Sustainability (2008) *Well-to-Wheels analysis of future automotive fuels and powertrains in the European context. Well-to-Tank Report Version 3. Ispra: Italy.*

Hammond G P & Jones C I (2019) *Inventory of carbon and energy v3.0 [online].*
https://circularecology.com/embodied-carbon-footprint-database.html
[Last accessed: May 2020]

Intergovernmental Panel on Climate Change (2006) *Guidelines for national greenhouse gas inventories. National Greenhouse Gas Inventories Programme, Intergovernmental Programme on Climate Change.*

Intergovernmental Panel on Climate Change (2007) *Climate change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press: Cambridge, United Kingdom and New York.*

International Standards Organisation (2008) *Carbon footprint of products – part 1: quantification; part 2: communication.*

International Standards Organisation (2013) *Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification and communication.*

Jones (2009) *Embodied Impact Assessment: the methodological challenge of recycling at the end of building lifetime, Construction Paper 248. Construction Industry Quarterly 11(3), pp 140-146.*

National Air Quality Archive (2009) *Glossary – oxides of nitrogen (NO_x) [online].*
http://www.airquality.co.uk/archive/glossary.php
[Last accessed: June 2009]

Nicholls J, McHale M & Griffiths R (2008) *Road Note 42: Best practice guide for durability of asphalt pavements. TRL Published Report. Wokingham: TRL Limited.*

Nicholls J, Carswell I, Thomas, C & Sexton, B (2010) *TRL 674: Durability of thin asphalt surfacing systems. Part 4: Final report after 9 years' monitoring. Wokingham: TRL Limited.*

Reeves S, Hewitt A & Pepler A (2020) *PPR960: Review and update of the asPECT carbon footprinting tool for asphalt road pavements. Wokingham: TRL Limited.*

Shively E B (2003) *The effects of dredging and trawling on continental shelf sediment biochemistry [online].*
http://hdl.handle.net/10161/273
[Last accessed: May 2011]

Strategic Rail Authority (2001) *Rail emission model. AEA technology Environment, Abingdon.*

Stripple H (2001) *Life cycle inventory of asphalt pavements. Sweden. IVL Swedish Environmental Research Institute Ltd. European Asphalt Pavement Association (EAPA) and Eurobitume.*

United Nations Environment Programme (2000) *The GHG Indicator: UNEP Guidelines for Calculating Greenhouse Gas Emissions for Businesses and Non-Commercial Organisations [online].*
http://www.unepfi.org/fileadmin/documents/ghg_indicator_2000.pdf
[Last accessed: September 2009]

World Resources Institute (WRI)/ World Business Council for Sustainable Development (WBSCD) *(2010) Greenhouse gas protocol initiative [online].*
http://www.ghgprotocol.org/standards/product-and-supply-chain-standard
[Last accessed: March 2011]

Waste & Resources Action Programme (unpublished data) *LCA of aggregates.*

Wayman M, Schiavi-Mellor I & Cordell B (2020) *Protocol for the calculation of whole life cycle greenhouse gas emissions generated by asphalt. TRL Published Report. Wokingham: TRL Limited.*