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PPR575

Protocol for the calculation of whole life cycle greenhouse gas emissions generated by asphalt

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Transport Research Laboratory

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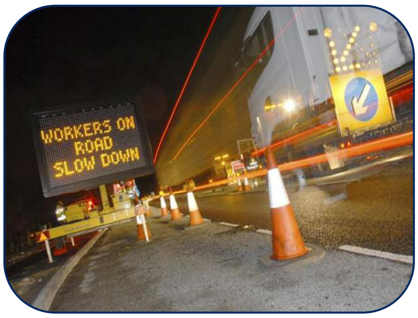


PUBLISHED PROJECT REPORT PPR575

Protocol for 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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Project Ref:	SCD 2011/05

Quality approved:

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Disclaimer

Contents amendment record

This report has been amended and issued as follows:

Version	**Date**	**Description**	**Editor**	**Technical Referee**
3.0	10/05/11	Final	MW	HV

Contents

Foreword

This protocol provides a clear set of rules, implemented in the accompanying software, to be used by producers of road materials, designers and contractors to calculate carbon dioxide equivalent (CO_2e) emissions associated with bitumen bound mixtures. This will fulfil the following functions:

- Assessment of the potential greenhouse gas (GHG) emissions of different alternatives at the procurement stage;
- Accounting of GHG emissions during and after construction.

This protocol was produced by the 2008-11 Collaborative Research Programme. Collaborative research is a joint initiative of the Highways Agency, Minerals Products Association, Refined Bitumen Association and TRL. The protocol considers the CO_2e impacts of building and maintaining a road pavement, from sourcing raw materials and laying mixtures to maintenance through periodic interventions to ultimate deconstruction. The protocol considers all emissions that contribute to climate change from sources including energy use, combustion processes, chemical reactions, service provision and delivery.

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 other information provided here. This protocol, the guidance document and the software constitute the asphalt Pavement Embodied Carbon Tool (asPECT), and replace the sets of deliverables delivered both in 2009 and 2010. This protocol follows the requirements of *BSI PAS 2050:2008* (British Standards Institution, 2008) and uses the latest Defra emissions factors for company reporting. A future aspiration is for the protocol to be adapted to conform to further life cycle reporting standards, such as the combined initiative of World Business Council for Sustainable Development (WBSCD) and World Resources Institute (WRI), and also that of the International Standards Organisation (ISO 14067), as they become available.

Further information is provided within the accompanying guidance notes (Wayman *et al.*, 2011) regarding the scope of the project and the life cycle stages which are covered. The 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.

The protocol is endorsed by the Highways Agency, MPA (Mineral Products Association), RBA (Refined Bitumen Association) and ADEPT (Association of Directors of Environment, Economy, Planning and Transport).

1 Scope

This protocol 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 2050:2008) 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.

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 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 (mixCO_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).

$$\mathbf{CO_2e\ (asphalt\ mixture) = constCO_2e\ + transportCO_2e\ + \ mixCO_2e\ + heatCO_2e}$$

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 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, extraction 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.

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 and 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.
- 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.

[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.

2.5.2 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.

2.5.3 Bituminous binders

2.5.3.1 Bitumen

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

2.5.3.2 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 should 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.

2.5.3.3 *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 should be accounted for in accordance with Section 2.9.

2.5.3.4 *Natural bitumen*

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

2.5.4 *Cementitious materials*

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

2.5.5 *Hydrated lime*

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

2.5.6 *Other constituent materials*

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

Exclusions

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

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 60:40 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.

$$\mathbf{CO_2e\ (asphalt\ mixture) = (\,(0.6\ \times mixCO_2e\,) + (0.4\ \times futCO_2e\,)\,)\ kgCO_2e/t}$$

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 ($futCO_2e$):

$$\mathbf{futCO_2e\ =\ vmixCO_2e - \left(R \times \left((b_M \times 190) + \left((100\% - b_M) \times 4.3\ \times 1.05\right) -\ futproRAP\right)\right) kgCO_2e/t}$$

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 4 $kgCO_2e/t$[7]. The factor of 1.05 is applied to reflect loss of virgin aggregate due to moisture and wastage (see Section 2.4). Thus Equation 3 is:

$$\mathbf{futCO_2e\ =\ vmixCO_2e - \left(95\% \times \left((b_M \times 190) + \left((100\% - b_M) \times 4.3\ \times 1.05\right) -\ 4\right)\right) kgCO_2e/t}$$

Equation 3

[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 4 $kgCO_2e/t$. This is the content that is specified for recycled aggregates in Defra/DECC's Greenhouse Gas Conversion Factors for Company Reporting[8]. It is anticipated that recycled aggregates and RAP will undergo a similar level of reprocessing.

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.

$$\mathbf{vmixCO_2e} = \mathbf{mixCO_2e} - (\mathbf{proRAP} \times \%\mathbf{RAP}) + \%\mathbf{RAP}\Big((\mathbf{Aggmix} \times \mathbf{1.05} \times (\mathbf{100\%} - \mathbf{b_R})) + (\mathbf{Bitmix} \times \mathbf{b_R})\Big)$$

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

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.

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:

$$\mathbf{F} = \frac{\mathbf{F_{tot}}}{\sum_{n=1}^{N} \frac{T_n k}{k_n}}$$

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:

$$\mathbf{F_n} = \mathbf{F} \times \frac{\mathbf{K}}{\mathbf{Kn}}$$

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:

$$F = \frac{F_{tot}}{\sum_{n=1}^{N} \frac{T_n t_n}{t}}$$

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:

$$F_n = F \frac{t_n}{t}$$

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:

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

Equation 9

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 'Grand Total GHG' emissions factors available within the most current version of Guidelines to Defra/DECC's Greenhouse Gas Conversion Factors for Company Reporting[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 'Grand Total GHG' emissions factors[8]:

$$\textbf{kg CO}_2\textbf{e per journey} = \textbf{Distance travelled (vkm)} \times \left(\textbf{Defra 50\% load factor [Total GHG}\frac{[\textbf{kgCO}_{2e}]}{[\textbf{vkm}]}]\right) - \left((\textbf{f} - \textbf{50\%}) \times \textbf{Defra 0\% load factor [Total GHG}\frac{[\textbf{kgCO}_{2e}]}{[\textbf{vkm}]}]\right)$$

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%.

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 'Grand Total GHG' emissions factor available in the latest version of Guidelines to Defra/DECC's Greenhouse Gas Conversion Factors for Company Reporting[8] shall be used.

[8] http://www.defra.gov.uk/environment/economy/business-efficiency/reporting/

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 'Grand Total GHG' emissions factor available in Guidelines to Defra/DECC's Greenhouse Gas Conversion Factors for Company Reporting[8].

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 'Grand Total GHG' emissions factor applied from Guidelines to Defra/DECC's Greenhouse Gas Conversion Factors for Company Reporting[8].

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

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 4.6 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 4.6 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 Guidelines to Defra/DECC's Greenhouse Gas Conversion Factors for Company Reporting[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.

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 Defra/DECC Greenhouse Gas Conversion Factors for Company Reporting[8,12] (Annex 9).

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 10 $kgCO_2e$ 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 Guidelines to Defra/DECC's Greenhouse Gas Conversion Factors for Company Reporting[8] (Annex 1) 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.

$$\textbf{Whole life carbon impact} = \frac{\textbf{CO}_2\textbf{e impacts Steps 1} - \textbf{10} \ (\textbf{kgCO}_2\textbf{e}/\textbf{t})}{\textbf{product lifetime (years)}}$$

Equation 11

Appendix A Converting grid electricity consumption to CO_2 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 'Grand Total GHG' grid rolling average conversion factor for electricity use (country specific, where necessary), which can be found within the most current version of Guidelines to Defra/DECC's Greenhouse Gas Conversion Factors for Company Reporting[8] (Annexes 3 & 10).
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_2 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 'Grand Total GHG' conversion factor (net calorific value basis) within the most current version of Guidelines to Defra/DECC's Greenhouse Gas Conversion Factors for Company Reporting[8] (Annex 1), which matches the fuel and unit you are using. If you cannot find a factor for that unit, Appendix F 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 'Grand Total GHG' emissions factor for the fossil fuel as specified in the section above ($EF_{\text{fossil fuel}}$).
   iii. Find the appropriate 'Grand Total GHG' biofuel emissions factor in Guidelines to Defra/DECC's Greenhouse Gas Conversion Factors for Company Reporting[8] (Annex 9).
   iv. Apply this equation:

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

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 Guidelines to Defra/DECC's Greenhouse Gas Conversion Factors for Company Reporting[8]:

   i. Obtain the fuel composition from the supplier and apportion the conversion factors provided in Guidelines to Defra/DECC's Greenhouse Gas Conversion

Factors for Company Reporting[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 Guidelines to Defra/DECC's Greenhouse Gas Conversion Factors for Company Reporting[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	0.1670	0.1660	0.1661	$kgCO_2$/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	1200	Industry average, 2009
Bitumen[13]	190	Eurobitume, 2011
Bitumen Emulsion (residual bitumen)[13,14,15]	220	Eurobitume, 2011
Cement (Portland Cement CEM I)	930 (CO_2 only)	BCA, CSMA, UKQAA, 2009
Explosives	3900	Estimate from IPCC Emissions Factors, 2006
Fibres	0.78	Industry average, 2009
Fluxes (kerosene based)[14]	370	European Commission, 2009
GGBS	83	Hammond & Jones, 2011
Hydrated Lime	780	Hammond & Jones, 2011
Natural Bitumen	TBA	-
PFA (as binder)	4.0	BCA, CSMA,UKQAA, 2009
Pigments	TBA	-
Polymer Modified Bitumen	370	Eurobitume, 2011
Polymer Modified Bitumen Emulsion (residual bitumen)[13,14,15]	350	Data collated by the Refined Bitumen Association
Water	0.30	Water UK, 2008
Wax (Fischer-Tropsch synthetic wax)	5700	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.

Appendix E Pre-combustion factors for energy use

The original pre-combustion factors presented in this Appendix have now been removed. Since Version 1.0 of asPECT, Defra/DECC have introduced 'Indirect GHG' emissions factors, as a component of 'Grand Total GHG' 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 2008-2009*	*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.*	*2009*	*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.*	*2011*	*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 and FT wax	*Estimate from European Joint Research Centre data.*	*Well-to-wheels LCI of transport fuels, FT wax estimated from coal to synthetic diesel process.*	*2008*	*EU representative (though some sources of wax maybe worldwide)*	*Coal-to-liquid and Fischer-Tropsch, based in the EU.*

Data point(s) *(secondary data)*	***Source(s)***	***Calculation Notes, Accuracy***	***Temporal considerations***	***Geographical specificity***	***Technological applicability***
CO_2e contents of supplied water	*Water UK*	*Average based on individual company reporting.*	*2007-2008*	*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 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, 2010)

Appendix H Updates to the protocol

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

- Whether any of the stated rules, calculation methodologies or guidance needs amending;
- Whether any of the default data or conversion factors need replacing, as new supporting evidence has arisen or been submitted for consideration in the past 12 months;
- 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 in the past 12 months.

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)	Ambient temperature (°C)	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	0	23.8	14.8	12.7	11.8	11.3	10.9	11.1	10.7	10.6	10.7																				
	15	14.7	9.3	8.0	7.5	7.2	7.0	7.0	6.8	6.7	6.8																				
	30	11.5	13.8	17.2	20.8	24.8	28.5	33.5	36.7	40.7	45.7																				
0.50	0	11.6	6.3	5.7	5.2	4.9	4.8	4.8	5.2	5.0	5.2	5.6	5.7	5.9	6.2	6.2	6.3														
	15	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														
	30	5.9	3.4	3.2	3.0	2.8	2.8	2.8	3.0	2.9	3.0	3.1	3.2	3.3	3.4	3.4	3.4														
1.00	0	11.8	6.4	4.6	4.0	3.7	3.6	3.4	3.4	3.5	3.4	3.4	3.4	3.5	3.4	3.5	3.5	3.5	3.6	3.6	3.9	3.9	3.9	4.0	4.0	4.0					
	15	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					
	30	6.0	3.5	2.7	2.4	2.3	2.2	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.2	2.2	2.2	2.2	2.2	2.4	2.4	2.4	2.4	2.4	2.4					
2.00	0	11.6	6.5	5.2	4.5	4.1	3.7	3.6	3.6	3.6	3.4	3.5	3.5	3.6	3.7	3.8	3.7	3.9	3.9	4.0	4.2	4.4	4.6	4.7	4.8	4.9	4.9	4.9	4.9	5.2	5.2
	15	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
	30	5.9	3.5	2.9	2.6	2.4	2.3	2.2	2.2	2.2	2.1	2.2	2.2	2.2	2.2	2.3	2.3	2.3	2.4	2.4	2.5	2.6	2.7	2.7	2.8	2.8	2.8	2.8	2.8	2.9	3.0
2.20	0	17.9	9.0	6.4	5.5	4.9	4.6	4.3	4.2	4.1	4.0	3.9	3.8	3.9	3.8	3.8	3.8	3.8	3.8	3.8	3.9	3.9	3.9	4.0	4.1	4.2	4.3	4.3	4.4	4.4	4.6
	15	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
	30	8.8	4.7	3.5	3.1	2.8	2.7	2.5	2.5	2.4	2.4	2.4	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.4	2.4	2.5	2.5	2.5	2.6	2.6	2.7

Acknowledgements

The work described in this report was carried out in the C4S Division of the Transport Research Laboratory. The authors are grateful to Steve Betteridge and Bob Noakes of CSS (ADEPT), John Barritt of WRAP and Wyn Lloyd of the Highways Agency for their input into the project, to Dr Rubina Greenwood and Dr Helen Viner, who carried out the internal technical reviews, and also to Dr Dorothy Maxwell of Global View Sustainability Services, Dr Tony Parry of Nottingham University and to Craig Jones of Sustain who carried out peer reviews of the documentation against the requirements of PAS 2050 at various stages in the project.

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.

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Protocol for the calculation of whole life cycle grenhouse gas emissions generated by asphalt

Specific contributions to climate change - "carbon footprints" - now feature in the claims of many products, giving a basis for potential customers to procure on environmental as well as economic terms. This paper describes a consistent approach to carbon footprinting devised for asphalt products, developed through a collaborative effort by the UK highways sector, with representation from clients, industry and the research community. The asphalt Pavement Embodied Carbon Tool (asPECT), which consists of protocol documentation and software, takes a life cycle approach that follows the Publically Available Specification PAS 2050:2008 and facilitates assessment of greenhouse gas contributions from raw material acquisition, through to product production, installation, maintenance and end-of-life. The method provides the resolution to allow factors such as individual constituent material contributions, recycled content, energy consumption in heating and mixing and transport modes to be reflected in the overall footprints of asphalt products and applications.

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ISBN 978-1-84608-981-7

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