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Published Project Report
PPR439

Protocol for the calculation of life cycle greenhouse gas emissions generated by asphalt used in highways

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Transport Research Laboratory

PUBLISHED PROJECT REPORT PPR439

Protocol for the calculation of life cycle greenhouse gas emissions generated by asphalt used in highways

Part of the asphalt Pavement Embodied Carbon Tool (asPECT)

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Contents

Foreword

This protocol provides a clear set of rules, implemented in the accompanying calculation tool, to be used by producers of road materials, designers and contractors to calculate carbon dioxide equivalent (CO_2e) emissions associated with different 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 represents the first phase of a larger project aimed at developing an industry standard for the calculation of the environmental impacts of building and maintaining a road structure, from sourcing raw materials and laying mixtures to reconstruction through regular maintenance interventions. The protocol considers all emissions which contribute to climate change from sources including energy use, combustion process, chemical reactions, service provision and delivery.

This first phase is concerned with the assessment of carbon dioxide equivalent emissions from the production of asphalt and use of it to construct highway courses, following the requirements of *BSI PAS 2050:2008* (British Standards Institution, 2008) and using the latest Defra emissions factors for company reporting. This protocol has been written so that further modules can be added to extend this methodology to other materials, a full road structure and its whole life. 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, 2009) regarding the scope of the project and the life cycle stages which are covered. The asPECT calculator 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, guidance and calculator together constitute the first three deliverables of the asphalt Pavement Embodied Carbon Tool (asPECT).

The protocol is endorsed by the Highways Agency, MPA (Mineral Products Association), RBA (Refined Bitumen Association), CSS (County Surveyor's Society) and WRAP (Waste & Resources Action Programme).

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 is made in terms of CO_2e per tonne of mixture, which is the functional unit chosen for use in the protocol.

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 combination of the cradle to gate and transport CO_2e from each of the constituent materials and ancillary materials[1] calculated in accordance with Sections 2.3, 2.4 and 2.7.
- 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 2.4.
- CO_2e arising from the process of heating and drying the mixture and its constituent materials, calculated in accordance with Section 2.6.

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 2.7.
- CO_2e associated with laying and compacting the material at the construction site (and related activities), calculated in accordance with Section 2.8.

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. Corporate off site and laboratory overheads are excluded from this calculation.

[1] 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.

2.3 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 2.4.

2.4 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.

The CO_2e per tonne involved in transporting each constituent material to the asphalt plant shall be calculated separately in accordance with Section 2.7.

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

2.4.1 Aggregates

2.4.1.1 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.

2.4.1.2 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[2], 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.

2.4.1.3 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[2] for all operation of fixed and loose plant.

2.4.1.4 Crushed rock / sand and gravel – land won offshore

Include:

- Energy use at the quarry/pit in accordance with Section 2.4.1.2 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 2.7.
- Processing energy at the wharf by type of fuel/energy including electricity generated on site and green tariff[2] for all operation of fixed and loose plant.

2.4.1.5 Recycled asphalt planings (RAP) and recycled aggregates

Recycled asphalt planings are awarded zero CO_2e emissions at the first facility where they are deposited after planing or bulk excavation of the asphalt from the old pavement.

[2] 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 B.

Similarly, inert waste to be processed into recycled aggregates is awarded zero CO_2e emission at the first facility where it is deposited.

All energy consumed thereafter in processing and transporting the RAP or recycled aggregate shall be accounted for.

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[2] for all operation of fixed and loose plant.

2.4.1.6 Manufactured aggregates (e.g. glass, PFA, slag, IBA)

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[2] 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;
- PFA: zero CO_2e shall be assumed for PFA as tipped from the precipitators of the power station for direct use as filler aggregate;
- 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.

2.4.2 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.

2.4.3 Bituminous binders

2.4.3.1 Bitumen

A default cradle to gate CO_2e figure for bitumen is provided in the default data in Appendix D[3].

2.4.3.2 Polymer modified bitumen (PMB) types

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

[3] 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.

2.4.3.3 Bitumen emulsions

Default cradle to gate CO_2e figures for bitumen emulsion and PMB emulsion are provided in the default data in Appendix D.

2.4.3.4 Synthetic binders

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

2.4.3.5 Natural bitumen

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

2.4.4 Cementitious materials

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

2.4.5 Hydrated lime

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

2.4.6 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.

2.5 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[2].

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.

2.6 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.

2.6.1 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 2.6.3 "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:

$$F = \frac{F_{tot}}{\sum_{n=1}^{N} \frac{T_n K}{K_n}} \qquad (1)$$

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:

$$F_n = F \frac{K}{K_n} \qquad (2)$$

An example is provided in Section 2.6.3 below.

2.6.2 *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:

$$F = \frac{F_{tot}}{\sum_{n=1}^{N} \frac{T_n t_n}{t}} \qquad (3)$$

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:

$$F_n = F \frac{t_n}{t} \qquad (4)$$

2.6.3 *Special processes*

It is necessary to calculate a notional production rate to feed in equation (1) 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 preheater;
- 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:

$$\text{Notional k} = \text{standard process rate} \times \frac{\text{standard product energy } (^{L}/_{t})}{\text{non-standard product energy } (^{L}/_{t})} \qquad (5)$$

Worked Example - Basic Methodology (continuous single dryer)

An example of the application of formulae (1), (2) and (5), 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 (4) 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:

F_1= 3.75 L/t x 200 tph/100 tph = 7.5 L/t
F_2= F = 3.75 L/t
F_3= 3.75 L/t x 200 tph/150 tph = 5 L/t
F_4 and F_5 are known from monitoring.

2.7 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 laying site.

CO_2e emissions from transport shall be calculated using the Defra GHG emission factors available within the most current version of *Guidelines to Defra/DECC's Greenhouse Gas Conversion Factors for Company Reporting*[4] and the pre-combustion figures for different fuels which are provided in Appendix E.

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

2.7.1 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 emissions factors[4]:

$$\text{kg CO}_2\text{e per journey} = \text{Distance travelled (vkm)} \times (\text{Defra 50\% load factor [Total GHG} \frac{[\text{kgCO}_{2\text{e}}]}{[\text{vkm}]}] - ((\text{f} - 50\%) \times \text{ Defra 0\% load factor [Total GHG} \frac{[\text{kgCO}_{2\text{e}}]}{[\text{vkm}]}] \quad (6)$$

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%.

The appropriate pre-combustion factor shall be applied to quantity of fuel consumed in the journey. The total emissions for the journey shall therefore comprise the direct emissions calculated in accordance with Equation (6) plus the pre-combustion emissions.

[4] http://www.defra.gov.uk/environment/business/reporting/conversion-factors.htm

Worked Examples - Transport

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

60 vkm x (0.9267 kgCO_2e/vkm – ((50% - 50%) x 0.7617 kgCO_2e/vkm))
= 55.60 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 (0.9267 kgCO_2e/vkm – ((65% - 50%) x 0.7617 kgCO_2e/vkm))
= 48.74kgCO_2e

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

60 vkm x (0.9267 kgCO_2e/vkm – ((35% - 50%) x 0.7617 kgCO_2e/vkm))
= 62.46 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 48.74 + 30% x 55.60 = 50.80 kgCO_2e

These calculated figures represent direct emissions, from combustion of the fuel. To this, pre-combustion emissions would need to be added. The easiest way to do this is to equate the emissions figure above to a quantity of fuel (diesel in this case), using the CO_2e density of diesel (Defra, 2009). For the 50% utilisation scenario:

55.60 kgCO_2e / 3200.6 kgCO_2e/t = 0.01737 t of diesel

Pre-combustion factors are provided for fuels in Appendix E. For diesel the figure to use is 418 kgCO_2e/t. Multiply this by the mass of fuel used above:

0.01737 x 418 kgCO_2e/t = 7.26 kgCO_2e

Hence the total CO_2e attributed to the journey should be:

pre-combustion emissions + direct emissions = total emissions

7.26 kgCO_2e + 55.60 kgCO_2e = 62.86 kgCO_2e

2.7.2 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 applied to the emissions factor available in the latest version of *Guidelines to Defra/DECC's Greenhouse Gas Conversion Factors for Company Reporting*[4] and the pre-combustion figures for different fuels which are provided in Appendix E.

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 applied to the most appropriate emissions factor available in Guidelines to *Defra/DECC's Greenhouse Gas Conversion Factors for Company Reporting*[4] and the pre-combustion figures for different fuels which are provided in Appendix E.

2.7.3 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 conversion factor applied from Guidelines to *Defra/DECC's Greenhouse Gas Conversion Factors for Company Reporting*[4] and the pre-combustion figures for different fuels which are provided in Appendix E.

2.8 Installation at the construction site

2.8.1 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 3.9 kgCO_2e per tonne of asphalt laid to reflect the fuel used in these processes or at a rate calculated in accordance with Section 2.8.2.
- In addition, the use of tack/bond coat and its transport to site shall be accounted for. Use of tack/bond coat should be included using cradle to gate CO_2e figures (default values for residual bitumen are available in Appendix D). Transport of the emulsion shall be accounted for in accordance with Section 2.7.

2.8.2 Specific Calculations

As an alternative to the standard rate of 3.9 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[4] as outlined in Appendix B and the pre-combustion factors in Appendix E.
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.

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 current calculated pre-combustion factor for electricity in Appendix E.

3. Identify the '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's Greenhouse Gas Conversion Factors for Company Reporting*[4] and add this to the pre-combustion factor.

4. Multiply the amount of electricity used by the combined emissions factor calculated in (3).

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.

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.

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):

1. Identify the appropriate '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*[4], 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.

2. Add to this factor the appropriate pre-combustion factor provided in Appendix E.

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

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

1. 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.

2. Find the combustion emissions factor for the fossil fuel as specified in the section above ($EF_{fossil\ fuel}$).

3. Add to this factor the appropriate pre-combustion factor provided in Appendix E ($PC_{fossil\ fuel}$).

4. Find the appropriate biofuel combustion factor in Appendix E ($EF_{biofuel}$; pre-combustion already included).

5. Apply this equation:

$$\text{Emissions factor for fuel (with a \% biofuel)} = (\%\ \text{biofuel} \times \text{EF}_{\text{biofuel}}) + \big((1 - \%\ \text{biofuel})) \times\ (\text{EF}_{\text{fossil fuel}} +\ \text{PC}_{\text{fossil fuel}})\big)\quad (7)$$

6. 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:

Calculate combustion emissions for fuels not listed within *Guidelines to Defra/DECC's Greenhouse Gas Conversion Factors for Company Reporting*[4] directly, although this will only provide an approximate value.

1. Obtain the carbon content of the fuel portion derived from crude oil, in grams per litre, from the fuel manufacturer.

2. The carbon content shall be multiplied by the ratio of the molecular weight of CO_2 (equal to 44) and the molecular weight of carbon (equal to 12), corrected by an oxidation factor of 0.99, to obtain CO_2 emissions in g/L, as follows (US EPA, 2005):

$$\text{CO}_2 \text{ emissions per litre of fuel } [{}^{\text{g}}/_{\text{L}}] = \text{Carbon content of oil} - \text{derived fuel portion } [{}^{\text{g}}/_{\text{L}}] \times 0.99 \times ({}^{44}/_{12}) \quad (8)$$

Other greenhouse gases emissions from burning these fuels might be released. For simplicity, it is assumed that the CO_2 emissions calculated as above are representative of the total GHG emissions associated with the burning of fuel.

3. Add to this an estimate of emissions released during pre-combustion processes.

d) Alternatively, for novel fuels only:

1. 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*[4], 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).

2. Add to this 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*[4] shall be submitted with supporting information to inform future versions of the protocol. Submissions can be made via sms@trl.co.uk.

Appendix C GHGs 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):

Data are in kg per tonne of blasted rock.

Emissions to atmosphere - Blasting fumes				
	from ANFO	from Emulsion	From Nitro	Units
CO_2	0.1670	0.1660	0.1661	kg/tonne fragmented rock

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[5] 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[5]	280	Eurobitume, 1999
Bitumen Emulsion (residual bitumen)[5,6]	340	Data collated by the Refined Bitumen Association
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)[6]	370	European Commission, 2009
GGBS	52	BCA, CSMA, UKQAA, 2009
Hydrated Lime	740	Hammond & Jones, 2008
Natural Bitumen	TBA	-
PFA (as binder)	4.0	BCA, CSMA,UKQAA, 2009
Pigments	TBA	-
Polymer Modified Bitumen	460	Data collated by the Refined Bitumen Association
Synthetic Binders[5]	TBA	-
Polymer Modified Bitumen Emulsion (residual bitumen)[5,6]	450	Data collated by the Refined Bitumen Association
Water	0.28	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

[5] 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 2.7 and included.

[6] 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.

Appendix E Pre-combustion factors for fuels

In accordance with PAS 2050:2008, emissions associated with the provision of energy sources need to be included. The following factors which account for the pre-combustion impacts of fuels have been derived, based on data from the European Commission (2009), European Joint Research Centre (2008) and Defra (2009). The global warming potentials are based on a 100 year time horizon and are sourced from the Inter-governmental Panel for Climate Change (IPCC, 2007).

Fuel	CO_2			CH_4			N_2O			Distribution CO_2e	Cradle to gate CO_2e
		GWP			GWP			GWP			($kgCO_2e/t$ fuel)
Diesel	301.927	1	302	3.360	21	71	0.006971	310	2	43	418
Petrol	593.230	1	593	3.606	21	76	0.014036	310	4	45	718
Fuel Oil	269.304	1	269	2.944	21	62	0.006223	310	2	41	375
Kerosene	259.313	1	259	3.300	21	69	0.005925	310	2	44	374
Light Fuel Oil	301.338	1	301	3.348	21	70	0.006958	310	2	41	415
Natural Gas	285.821	1	286	6.906	21	145	0.005470	310	2	257	690
Hard Coal	105.775	1	106	7.933	21	167	0.005071	310	2	28	302
Naptha	338.563	1	339	3.346	21	70	0.007874	310	2	45	456
LPG			179							197	376
Wood Pellets	(Includes direct emissions)										122
Biodiesel (methylester)	(Includes direct emissions)										3215
Biodiesel (HVO)	(Includes direct emissions)										3801
Bioethanol	(Includes direct emissions)										2272
BioETBE (refinery)	(Includes direct emissions)										3077
BioETBE (non-refinery)	(Includes direct emissions)										3077
Electricity											0.0367 (**kg per kWh**)

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 in the year prior to publication 2008-2009.	Actual suppliers of UK asphalt companies.	Unknown
Collated data on CO_2e contents of bituminous products	Data collated by the RBA to protect the confidentiality of its members.	Averages of collected data (work ongoing to provide a more precise estimate in 2010)	Sourced in the year prior to publication 2008-2009.	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	Eurobitume published source	Single data point calculated from life cycle inventory.	1999 (work ongoing to provide an updated value in 2010)	European blend: 70% Middle Eastern/ 30% Venezuelan.	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, 2009)

Appendix H Updates to the protocol

The protocol and accompanying guidance documents 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.

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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.

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Protocol for the calculation of life cycle greenhouse gas emissions generated by asphalt used in highways

This project is part of the 2008-11 Collaborative Research Programme. Collaborative research is a joint initiative of the Highways Agency, Minerals Products Association, Refined Bitumen Association and TRL.

This protocol provides a clear set of rules, implemented in the accompanying calculation tool, to be used by producers of road materials, designers and contractors to calculate carbon dioxide equivalent (CO2e) emissions associated with different bitumen bound mixtures, fulfilling 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.

Further information is provided within the accompanying guidance notes (PPR440; Wayman et al., 2009) regarding the scope of the project and the life cycle stages which are covered. The asPECT calculator 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, guidance and calculator together constitute the first three deliverables of the asphalt Pavement Embodied Carbon Tool (asPECT).

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