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Further guidance to accompany the protocol for the calculation of life cycle greenhouse gas emissions generated by asphalt used in highways

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Transport Research Laboratory

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Further guidance to accompany the 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 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. Recognising the importance of sustainability issues for industry as a whole, the project team and focus group set out to create a 'sustainability management system' for the highways sector. Initial scoping soon prioritised greenhouse gas (GHG) measurement as the key sustainability issue and this became the initial focus of the project: to create a standardised method of measuring the contribution to climate change which highway products and applications make and to achieve endorsement from the sector in doing so.

The regulatory context for GHG reporting is becoming ever more challenging in terms of requirements. Commencing in April 2010, larger energy consumers will have to report carbon dioxide (CO_2) emissions to meet the requirements of the Carbon Reduction Commitment; local authorities and local authority partnerships will be required to report CO_2 emissions against a 2008-09 baseline in accordance with the National Indicator set (indicators 185 and 186), and uptake of the voluntary Carbon Disclosure Project, which has perhaps the most involved reporting requirements, is gathering pace. In addition to this, for client organisations, carbon awareness has translated into requirements for suppliers which are considered at the procurement stage and hence carbon has become another potential marketing tool for industry. It is hoped that the outputs of this project will assist in capturing the data which is required and facilitates the necessary calculations for clients, industry and wider stakeholders for product level assessment.

This document accompanies the protocol for calculating the life cycle greenhouse gases in asphalt (Wayman et al, 2009) as used in highways. It is designed to provide extra interpretation and justification of the clauses within the protocol and to demonstrate how applicable sections of the *Publically Available Specification for the Assessment of the Life Cycle Greenhouse Gas Emissions of Goods and Services* (PAS 2050:2008; British Standards institution, 2008) have been followed. Both the protocol and guidance documents also make reference to the *Defra/DECC Guidelines to Defra's GHG conversion factors for company reporting*. The normative references for these documents are *Environmental Management – Life Cycle Assessment – Requirements and Guidelines* (BS EN ISO 14044:2006) and the *Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006) respectively.

The accompanying asPECT 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 and the information provided here. The protocol, guidance and calculator together constitute the first three deliverables of the asphalt Pavement Embodied Carbon Tool (asPECT).

This first phase is concerned with the assessment of GHG emissions, expressed in CO_2 equivalents, from the production of asphalt and use of it to construct highway courses. The assessment does not yet consider the full life cycle of asphalt. Further modules will be developed to extend this guidance as the protocol extends to include the full road structure and its whole life. The current scope in terms of a generic ten step life cycle for asphalt which has been utilised in this project is represented by the red boundary in Figure 1.1. The protocol considers all emissions which contribute to climate change from sources including energy use, combustion process, chemical reactions, service provision and delivery.

In considering just this first phase, it is recognised that the analysis constitutes at present a 'partial GHG emissions assessment', as defined within the Publicly Available Specification (PAS) 2050, and will mainly be used to provide information between different parties in the supply chain (business to business communications). It is intended that manufacturers will make self declarations of emissions in the first instance. These declarations can then be verified by third parties at a later date as required.

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

Use

Figure 1.1 Ten step asphalt life cycle indicating scope

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

A future aspiration is for the protocol to be adapted to conform to further life cycle reporting standards, such as the joint Product and Supply Chain Initiative of the 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.

In addition to the commissioning partners, the protocol has been endorsed by both CSS (County Surveyor's Society) and WRAP (Waste & Resources Action Programme), who participated in its development.

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

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.

Explanatory Notes - Scope

What is CO_2e and why is it used?

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

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

Why are suppliers and sub-contractors emissions included?

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

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

What is embodied CO_2e (or embodied carbon)?

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

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

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

2 Requirements

2.1 Asphalt mixture

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

- *The 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 2.5.*
- *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. *Energy consumption from office and laboratory overheads shall be excluded from the 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.

Explanatory Notes - Requirements

What is the reason for the exclusions?

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

Section 6.4.3 of the PAS justifies the exclusion of capital goods within the calculation.

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

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

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

Worked Example - Requirements

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

Coarse Aggregates: 700 kg = 70%

Fine Aggregates: 150 kg = 15%

Filler: 100 kg = 10%

Bitumen binder: 50 kg = 5%

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

The filler used arises from the plant itself.

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

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

The associated transport CO_2e is 62.86 kgCO_2e (55.60 direct emissions + 7.26 pre-combustion) /20t (payload) = 3.14 kgCO_2e/t (the example in Section 2.7 shows how this is calculated).

The filler has zero cradle to gate CO_2e and zero transport CO_2e (see Section 2.4.2).

The bitumen has the following cradle to gate CO_2e: 280 kgCO_2e/t (see Appendix D).

The associated transport CO_2e is 209.5 kgCO_2e (185.3 direct emissions + 24.20 pre-combustion) /20t (payload) = 10.5 kgCO_2e/t (based on example in Section 2.7, with distance travelled equal to 100 vkm x 2 = 200 vkm).

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

((700 + 150) x (1+5%) [kg] x (2.06+3.14) [kgCO_2e/t] + 100 [kg] x (0+0) [kgCO_2e/t] + 50 [kg] x (280 + 10.5) [kgCO_2e/t])/1000 [kg] =

= 19.2 kgCO_2e/t

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 2.7.2.*
- *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.

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:

[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.

- *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.

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.

[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.

2.4.5 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.

Explanatory Notes – Constituent materials

For information about methods to convert energy and fuels into CO_2e, please consult the Explanatory Notes to Section 2.5.

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

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

Why are overburden removal and restoration incorporated?

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

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

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

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

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

What about recycled asphalt planings (RAP) and aggregates which are recycled in a closed-loop?

In assigning emissions on the basis of limits of responsibility, GHG emissions associated with winning and transporting planings to the first processing site is considered responsibility of the contractor taking the road material up (which requires disposal), and is therefore part of maintenance/disposal processes which are not yet covered by this protocol. In making this distinction, the practical issue of asphalt manufacturers often not knowing/not being able to distinguish where the planings in the feedstock stockpile might come from, in order to assign upstream impacts, is eliminated.

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

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

Explanatory Notes – Constituent materials (continued)

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

The material contribution of these materials to the life cycle GHG emissions of the product are anticipated to be significantly less than the 1% cut-off which is recommended by the specification. The threshold of materiality for petroleum based lubricants has been calculated as in excess of 2.5 L of lubricant per tonne of asphalt. If this threshold were exceeded then consumables should be included in the assessment, however, for this version of the protocol we are assuming that the threshold is not exceeded until further evidence can be collected which indicates otherwise.

Section 3.33 of the PAS states the materiality threshold of 1%.

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

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

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

Which process steps do the default data include?

The default CO_2e figures include all processes from extraction of raw materials through to the point where they can be used in the asphalt mix, not including transport to the asphalt plant which should be specified separately. In terms of the ten step representation in Figure 1.1, the first three steps would be considered in generating default data, producing a 'cradle to gate' analysis for these constituents.

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

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

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

No. Bitumen is treated in the same way as all other constituent materials. Embodied energy reflects the energy expended in sourcing, transporting and processing bitumen to the point where it is ready to be utilised in an asphalt mix. The inherent potential energy of bitumen is not released by combustion during the highway life cycle and is therefore not included in the CO2e assessment. Should this framework be extended to consider resource depletion as an impact, in addition to contribution to climate change, then this depletion of energy bearing resources would become a relevant consideration. Stripple (2001) provides wider discussion on the inherent energy content of bitumen and its implications for impact assessment studies.

Worked Example – Overburden Removal

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

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

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

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

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

Worked Example - Restoration

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

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

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

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

And:

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

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

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

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

2.5 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.

<u>Explanatory Notes – Processing energy</u>

Why does energy consumption have to be split by fuel?

It is necessary for all energy used to be reported by type (e.g. electricity, gas, refuse derived oil etc.) to assign the correct emission factors in order to calculate CO_2e. The accompanying calculation tool uses the latest *Guidelines to Defra's Greenhouse Gas Conversion Factors for Company Reporting – Annexes* (Defra, 2008).

Why is last year's energy consumption data used?

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

How is green tariff electricity accounted for?

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

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

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

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

Non-CO_2 gases are included in fuel use emissions factors by virtue of using the 'Total GHG' emissions factors available in the most current version of *Guidelines to Defra/DECC's Greenhouse Gas Conversion Factors for Company Reporting[4].*

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:

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

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*	1_5
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 (5) 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.*

Explanatory Notes – Heating and drying energy

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

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

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

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

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

NE - not estimated

2.7 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]:

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

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:

$60 \text{ vkm} \times (0.9267 \text{ kgCO}_2\text{e/vkm} - ((50\% - 50\%) \times 0.7617 \text{ kgCO}_2\text{e/vkm}))$
$= 55.60 \text{ kgCO}_2\text{e}$

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:

$60 \text{ vkm} \times (0.9267 \text{ kgCO}_2\text{e/vkm} - ((65\% - 50\%) \times 0.7617 \text{ kgCO}_2\text{e/vkm}))$
$= 48.74 \text{kgCO}_2\text{e}$

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

$60 \text{ vkm} \times (0.9267 \text{ kgCO}_2\text{e/vkm} - ((35\% - 50\%) \times 0.7617 \text{ kgCO}_2\text{e/vkm}))$
$= 62.46 \text{ kgCO}_2\text{e}$

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:

$$70\% \times 48.74 + 30\% \times 55.60 = 50.80 \text{ kgCO}_2\text{e}$$

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_2*e density of diesel (Defra, 2009). For the 50% utilisation scenario:*

$$55.60 \text{ kgCO}_2\text{e} / 3200.6 \text{ kgCO}_2\text{e/t} = 0.01737 \text{ t of diesel}$$

Pre-combustion factors are provided for fuels in Appendix E. For diesel the figure to use is 418 $\text{kgCO}_2\text{e/t}$*. Multiply this by the mass of fuel used above:*

$$0.01737 \times 418 \text{ kgCO}_2\text{e/t} = 7.26 \text{ kgCO}_2\text{e}$$

Hence the total CO_2*e attributed to the journey should be:*

pre-combustion emissions + direct emissions = total emissions

$$7.26 \text{ kgCO}_2\text{e} + 55.60 \text{ kgCO}_2\text{e} = 62.86 \text{ kgCO}_2\text{e}$$

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.

Explanatory Notes - Transport

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

Yes. This acknowledges the fact that there are impacts incurred in the life cycle of fuels up to the point of combustion – the upstream impacts - associated with the provision of fuels (e.g. mining, transport and refining). The complexity of these activities has necessitated the use of a 'pre-combustion' emission factors for different fuels. These values have largely been derived from the European Reference Life Cycle Database (European Commission, 2009). Hence an emissions factor for any fuel will consist of the Defra emissions factor plus the pre-combustion factor. These figures are presented in Appendix E.

Section 6.4.2 of the PAS stipulates for the inclusion of emissions associated with the provision of energy sources.

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

Non-CO_2 gases are included in fuel use emissions factors by virtue of using the 'Total GHG' emissions factors available in the most current version of *Guidelines to Defra/DECC's Greenhouse Gas Conversion Factors for Company Reporting[4].*

How does the transport equation work?

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

2.8 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.*

Explanatory Notes – Installation

How and why was a standard figure devised?

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

The standard figure resulted from a working group in which 6 contracting companies were represented (Aggregate Industries, Cemex, Colas, Lafarge, Ringway and Tarmac). The figure was arrived at by taking the average of a number of measurements of fuel consumption on site by 3 companies. Fuel consumption was measured from on site fuel bowsers and equated to the amount of material laid. Site mobilisation was also quantified and included in the figure.

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

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:

$$Emissions\ factor\ for\ fuel\ (with\ a\ \%\ biofuel) = \left(\%\ biofuel \times EF_{biofuel}\right) + \left((1 - \%\ biofuel)) \times \left(EF_{fossil\ fuel} + PC_{fossil\ fuel}\right)\right) \quad (7)$$

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):

$$CO_2\ emissions\ per\ litre\ of\ fuel\ [^g/_L] = Carbon\ content\ of\ oil - derived\ fuel\ portion\ [^g/_L] \times 0.99 \times (^{44}/_{12}) \qquad (8)$$

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.

Explanatory Notes – Default Data Values

Why are some values marked "TBA"?

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

How is the default data selected or derived?

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

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

Appendix E Pre-combustion factors for energy use

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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Further guidance to accompany the 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 document accompanies the protocol for calculating the life cycle greenhouse gases in asphalt (PPR439; Wayman et al., 2009) as used in highways. It is designed to provide extra interpretation and justification of the clauses within the protocol and to demonstrate how applicable sections of the Publically Available Specification for the Assessment of the Life Cycle Greenhouse Gas Emissions of Goods and Services (PAS 2050:2008; British Standards institution, 2008) have been followed.

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 and the information provided here. The protocol, guidance and calculator together constitute the first three deliverables of the asphalt Pavement Embodied Carbon Tool (asPECT).

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