Title:

Review of Default Emissions Factors in Draft Stationary Energy and Industrial Processes Regulations: Coal

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1. Introduction

As part of development of a New Zealand Emissions Trading Scheme (ETS), draft Climate Change (Stationary Energy and Industrial Processes) Regulations have been developed to set out methods for those involved in Stationary Energy and Industrial Process sectors to monitor and calculate emissions from their activities.

The draft regulations include a schedule of default emissions factors for participants to use when calculating their total emissions from particular activities. In the case of coal, this includes default factors to be used when calculating emissions for importing and mining different types of coal.

In addition, regulations are to be developed allowing participants to apply for a unique emissions factor to apply instead of the default factor when calculating their total emissions for importing or mining coal under the regulations.

The Ministry for the Environment has contracted CRL Energy Ltd to provide expert advice to review the emissions factors for importing and mining coal to ensure those factors are robust and reliable. The purpose of this report is to:

1. Provide and check calculations used to develop default emissions factors and check the default emission factors against credible information for typical New Zealand coals, including the variability of coal properties.

2. Check calculations used to develop emissions factors used for importing coal to New Zealand, and checking default factors against credible information for imported coal, including variability of individual coal properties.

3. Provide information on testing and verification processes/procedures and standards that can be used by companies to assess samples of imported and mined coal in order to apply for a unique emissions factor.

4. Provide a brief overview on fugitive coal seam methane emissions from New Zealand coal mining including factors that may affect emissions, measurements and sampling methods that can be used to assess emissions[1].

2. Assessing Coal Properties

To understand how coal emission factors are influenced by various coal properties, it is important to summarise the different ways that coal geologists, suppliers and users around the world assess the relevant coal properties.

Coal is a mixture of organic matter (the source of combustion heat), mineral matter and moisture. The heat of combustion of a coal sample is usually measured in New Zealand as the gross calorific value, expressed in megajoules per kilogram of fuel (MJ/kg). The calorific

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[1] At this stage, this information is at a high level. More detailed work reviewing default emissions factors for fugitive coal seam methane may be sought at a later stage.

value of the organic matter is effectively diluted by the quantities of mineral matter (expressed as percentage ash content) and moisture (expressed as a percentage). The measurements of moisture and ash (together with volatile matter and fixed carbon[2] not relevant here) are collectively known as proximate analysis.

Coal ash content varies according to the amounts of mineral matter within the mined coal, either inherent or from thin mineral bands, and if there is any washery treatment. Moisture content varies according to the mining, transport and storage methods (including any washery treatment). So the proximate analysis and calorific value (expressed on an "as received basis") are useful for coal users and suppliers to understand the combustion heat that can be obtained from a particular consignment of coal.

For most coalfields, expressing the calorific value on a "dry ash free basis" can act as a useful check because removing the variability of the ash content and the moisture content usually leaves a consistent quantity that represents the heat content of the organic matter alone. Geologists reduce the variability of the heat content a little further by calculating the calorific value on a "dry mineral matter free basis" (distinguishing between the original mineral matter and the ash content resulting from combustion).

Another measurement that is useful for the geological assessment of different coalfields is the ultimate analysis[3], particularly the carbon content expressed as a percentage (usually on a "dry basis"). Again, removing the variability of the ash content and the moisture content usually leaves a consistent quantity that represents the carbon content of the organic matter alone. A useful reference is ISO 1170:1977 Coal – calculation of analyses to different bases.

The most common basis for reporting laboratory analyses is the "air dried basis". The moisture loss is measured after a crushed sample is conditioned to the laboratory atmosphere and this process minimises the risk that the moisture content of the sample will change during sample fine grinding, weighing and measurement for different properties. To ensure that moisture variability is accounted for, the moisture content of the laboratory sample is re-measured if, for example, the ultimate analysis is conducted on a different day from the proximate analysis. According to standard methods, the "loss on air drying" for a crushed sample is added to the laboratory measurement of air dried "moisture content" to give "total moisture", which is used for calculating properties on an "as received basis" for the coal consignment. Total moisture can also be measured by direct methods.

Proximate and calorific value analysis compilation

The Coal Association of NZ (Inc.) has funded the preparation of its "Coal Analysis Update" for over 20 years, most recently in 1999 and in 2004 (and scheduled for 2009). To prepare this summary of properties for most of the working mines in New Zealand, CRL Energy has relied on a combination of supplier provided proximate and other analyses for most of the larger mines and analyses from a Sampling Programme for the remaining mines.

For several years, the Ministry of Economic Development has provided on a confidential basis the annual production tonnages for each mine for national inventory purposes. CRL Energy has then been able to calculate production weighted average calorific values for exported and non-exported bituminous, sub-bituminous coals and lignite (based on the last available Coal Analysis Update).

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[2] Fixed carbon is simply calculated as the percentage of residue remaining after the volatile matter test. It is sometimes confused with ultimate analysis carbon content but much of the volatile matter also contains carbon.

[3] Ultimate analysis represents the chemical analysis of the organic matter, where carbon, hydrogen, nitrogen and sulphur contents are measured and the oxygen is calculated by difference once the coal moisture and ash content have been subtracted. A small correction is sometimes needed for carbonates in the mineral matter but no significant amounts have been found in New Zealand coals.

In general, average coal properties for each mine do not change significantly over many years. Major exceptions occur if the mining method changes or there is a distinct change in the coal seam organic or mineral matter or a coal washery is utilised to reduce the mineral content. Consequently, if there are no major shifts in the proportions from each mine, the tonnage weighted average coal properties for New Zealand exported and non-exported bituminous, sub-bituminous coals and lignite change relatively little from year to year.

Ultimate analysis compilation

In contrast with proximate and other analysis compilation, there has been little call until now for a compilation of ultimate analyses of New Zealand coals. In 1990, the Coal Research Association of NZ (Inc.), our predecessor organisation, prepared the first published estimates of CO_2 emissions from the New Zealand energy sector (Whitney and Hennessy 1990). At that stage, there had been a number of ultimate analyses performed on Sampling Programme coals and there was some detailed oxidation research conducted on others (Hennessy 1987).

Although there was evidence of weathering (oxidation) in some samples, it was believed the information was sufficiently complete to include a table of average carbon content for the three classes of high volatile bituminous coals, three classes of sub-bituminous coals and two classes of lignite used in New Zealand. Later, Baines used this table as the basis for his NZ Energy Information Handbook emission factor calculations (Baines 1993):

- 88.8 tonnes CO_2 per gross terajoule for bituminous coal[4],
- 91.2 tCO_2/TJ for sub-bituminous coal and
- 95.2 tCO_2/TJ for lignite.

There has been no comprehensive compilation of carbon contents for NZ coals since the 1990 report (which was weighted on 1988 coal production). However, there was an important addition to the available information when Solid Energy produced for officials a compilation of borehole carbon analyses for its current and prospective coalfields in 2004, later published in an appendix to its submission on the ETS (Solid Energy 2008).

For the current compilation, we are grateful to Solid Energy geologists who were able to provide some further analyses to update the 2004 report. We are also grateful to Richard Sykes of GNS Science for allowing access to unpublished coal analyses from an outcrop and lithotype sampling programme he undertook in 2004 (Sykes 2004). Neither borehole samples nor outcrop or lithotype face samples are directly comparable to the Coal Association Sampling Programme representative mine samples, but they add useful information for summarising the characteristics of some coals.

Assessing coal rank

Coal rank is the term used to describe the degree of completeness of the coalification process, which is essentially the compression of the original peat-like organic matter over millions of years under pressure and temperature to remove moisture and increase the carbon and hydrogen content. The spectrum of solid fuels includes the following (in increasing coal rank): peat, lignite (or brown coal), sub-bituminous coal, bituminous coal and anthracite.

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[4] Or kilograms CO_2 per gigajoule or grams CO_2 per megajoule. The New Zealand convention is to base the emission factor on the gross calorific value (or higher heating value). The European convention (followed in the IPCC Guidelines) is instead to use the net calorific value (or lower heating value) so IPCC CO_2 emission factors from coal are 5% higher than the equivalent gross emission factors used in New Zealand.

Geologists in New Zealand usually use the ASTM (US developed) coal classification system to define the sub-categories that explain coal properties and assist in the modelling of the size and quality of coal resources. However, the IPCC inventory guidelines (IPCC 1996 and 2006) use IEA definitions, which set different cut-off boundaries, are much broader and somewhat contradictory.

The CRANZ report (Whitney and Hennessy 1990), on which the Baines (1993) figures were calculated, was based on the ASTM rank definitions. They have also been the basis for calculations undertaken for MED's Energy Data File. For international consistency, it is timely to review the classification, move to the IPCC definition and assess whether there is a significant shift in average coal properties for New Zealand.

Table 1 Definitions of coal used in the IPCC 2006 Guidelines (Adams 2008)

Anthracite	A high rank coal used for industrial and residential applications [not in NZ]. It has generally less than 10% volatile matter and a high carbon content. Its gross calorific value is greater than 23.865 MJ/kg on an ash free but moist basis.
Coking coal	Bituminous coal with a quality that allows the production of a coke suitable to support a blast furnace charge. Its gross calorific value is greater than 23.865 MJ/kg on an ash free but moist basis.
Other bituminous coal	It is used for steam raising purposes and includes all bituminous coal that is not included under coking coal. It has a higher volatile matter than anthracite (more than 10%) and lower carbon content. Its gross calorific value is greater than 23.865 MJ/kg on an ash free but moist basis.
Sub-bituminous coal*	Non-agglomerating [non-coking] coals with a gross calorific value between 17.435 and 23.865 MJ/kg (on an ash free but moist basis) and more than 31% volatile matter (on a dry mineral matter free basis).
Lignite	A non-agglomerating [non-coking] coal with a gross calorific value of less than 17.435 MJ/kg (on an ash free but moist basis) and more than 31% volatile matter (on a dry mineral matter free basis).

* Note that NZ sub-bituminous (non-coking) coals range up to 26.7 MJ/kg (moist ash free).

The ASTM classification methodology allows the identification of several sub-bituminous coals (including eight mainly large mines in New Zealand) that fall in a confusing category between the sub-bituminous and bituminous categories under the IEA classification. They are all non-agglomerating[5] and low vitrinite reflectance (IPCC 1996) but they have gross calorific values (ash free bed moist basis[6]) ranging from 24.3 to 26.7 MJ/kg. CRL Energy

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[5] Agglomerating (coking) coals form a plastic coke-like material when subjected to high temperatures with limited access to air. The most common and simplest test is ISO 501:2003 Hard Coal – determination of the coal swelling number. High value coking coals swell to more than 10 times their original sample volume, poor quality bituminous coals form a plastic mass with very little swelling and sub-bituminous coals do not form a plastic mass at all.

[6] Ash free bed moist basis is difficult to estimate because it relies on having a good understanding of the bed (in-ground) moisture, which requires careful borehole sampling techniques (to prevent

recommends that the non-agglomeration characteristic is the paramount distinction and all of these coals will continue to be defined as sub-bituminous.

Similarly, the ASTM cut-off for lignite classification is significantly higher (19.3 MJ/kg) than the IEA one (17.4 MJ/kg). Fortunately there is only one medium sized active mine in New Zealand that falls between these limits. CRL Energy recommends that this mine will now be included in the sub-bituminous category and the effects of this amended methodology on average lignite and sub-bituminous coal gross calorific values for two selected years are summarised in Table 2.

Table 2 – Comparison of ASTM vs IEA lignite definition on average NZ calorific values

	2002 production weighted CV (MJ/kg, as received)	2007 production weighted CV (MJ/kg, as received)
Lignite (ASTM definition)	15.86	15.85
Lignite (IEA definition)	15.21	15.14
Sub-bituminous coal (ASTM definition)	22.44	22.35
Sub-bituminous coal (IEA definition)	22.36	22.27

The figures show that the removal of this mine's production from the lignite category significantly reduces the production weighted average calorific value (by about 4%) for both 2002 and 2007. Adding it to the sub-bituminous category results in a much less significant reduction (about 0.4% for both 2002 and 2007) because the sub-bituminous tonnage is nearly ten times the remaining lignite tonnage.

Coking coals

After consultation within the New Zealand coal industry, CRL Energy recommends that the IEA definitions of coking versus other bituminous coals are not practical for New Zealand: under ASTM classification, all bituminous coals are coking coals. There is no IEA definition of what coking properties are "suitable to support a blast furnace charge". Some weakly coking coal can be mixed with strongly coking coal from the same mine to produce a blended coal that has a premium value in the coking coal market. Strongly coking coals are exported for production of high value non-coke products such as activated carbon and ferrosilicon. Some of the bituminous coals exported as thermal power generation coals have coking properties that would mean that they could also be sold in the coking coal market.

For this report, CRL Energy continues to make the distinction used for the Energy Data File of exported bituminous coal versus bituminous coal produced for New Zealand use[7]. In the absence of any publically available coal shipment analyses, this distinction is based on an approximation that nearly all Stockton and Roa mine output is exported and the remaining

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moisture loss). Bed moisture is often more than as received moisture for lignites (because they partly dry once mined) and sometimes less than as received moisture for bituminous coals (after rain or if water is used in mining or washing).

[7] "Bituminous coal produced for New Zealand use" is more appropriate than the previous definition "Bituminous coal used in New Zealand", which should have included imported bituminous coal.

exported coal comes from Spring Creek. This assumption is likely to be somewhat inaccurate because it is unknown what proportion of exported coal comes from other mines (which generally have lower heat content). As an extreme example, there has been a recent public announcement of Ohai coal fines being railed to Lyttelton for export; without knowing the shipment size and relatively low calorific value of this wet fine coal, the current methodology would over-estimate the exported heat content (and consequent CO_2 emissions).

This may be a source of significant bias for the Energy Data File and the National Greenhouse Gas Inventory and should be investigated further. To improve the methodology, it is recommended that MED survey Solid Energy and Francis Mining (and Pike River Coal in future) for information on the range of properties (and quantities) of their exported coal shipments.

This survey would help reduce the major source of uncertainty associated with the emissions inventory for the coal sector: in particular, the moisture content figures for coals in the Analysis Update (2004) represent approximate averages for a range of screened, trucked and stockpiled coals. In the absence of better information on moisture variability, these figures have had to be used for estimating export coal shipments in 2008 and a correction has been estimated to compensate for part of the bias discussed above.

The effect of this correction is to reduce average gross calorific value by 0.68 MJ/kg below the exported bituminous coal value that would have been calculated from the previous methodology. (Applying a similar correction to 2007 figures would have resulted in a figure 0.40 MJ/kg below the exported bituminous coal value published in the Energy Data File.)

3. Coal Testing and Standards Relating to CO_2 Emissions

Coal sampling and testing according to various standard methods are well established in New Zealand for all the relevant analyses relating to CO_2 emissions from coal combustion. IANZ (International Accreditation NZ) has a procedure for accrediting laboratories[8] by checking regularly that their methods follow various standards or appropriate in-house methods. Similarly, NATA has 31 Australian laboratories currently accredited for the sampling and testing of coal.

CRL Energy has prepared a list of ISO, US ASTM and Australian AS standards in Appendix A that are likely to provide equivalent assurance of coal sampling, preparation and analysis procedures relevant to this report. Inter-laboratory reproducibility would be a much more significant source of variability than any differences among these standards.

Coal sampling and preparation

The most important steps in coal testing are associated with ensuring that correct sampling and preparation procedures have been used so that the coal powder contained in a small bottle can represent, for example, a coal shipment as large as 50,000 tonnes. The largest errors in coal analysis are in sampling. The ISO sampling standard or the equivalent BS (British), AS (Australian), ASTM (US) or other standard is an important pre-requisite before individual coal tests are considered.

A key quantity determined during coal preparation is the loss on air drying to determine the moisture loss when a crushed sample (typically up to 3mm particle size) is equilibrated in the laboratory atmosphere before grinding it to a powder (typically up to 0.2mm).

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[8] NZS ISO/IEC 17025: 2005 General requirements for the competence of testing and calibration laboratories.

IANZ currently has one laboratory accredited for its sampling/preparation method: CRL Energy (Gracefield) follows ISO 18283:2006 for hard coal sampling. The SGS quality manager stated that they follow an ISO sampling standard but they are not accredited for this. An expert in coal quality systems (Daly 2009) highlighted that both CRL Energy and SGS labs follow standard methods for coal preparation but only some sampling methods in some situations could be accredited. Many samples received by all laboratories are sampled by the coal mining companies so the sampling quality assurance lies with those companies.

Proximate and calorific value analysis

In addition to carbon analysis, the measurements of gross calorific value, moisture and ash content on a laboratory air dried sample are necessary for calculating a coal's CO_2 emission factor.

IANZ lists three laboratories accredited for conducting their proximate and calorific value analysis according to prescribed standards. CRL Energy measures calorific value using ISO 1928:1995, total moisture using ISO 5068:1983, moisture using ISO 11722:1999 and ash content using ISO 1171:1997. SGS (both Ngakawau and Waihi laboratories) measure calorific value using ISO 1928:1995 and proximate analysis using ASTM D5142-2004 (modified).

One means of determining inter-laboratory reproducibility of results is to participate in international round robin coal analysis on a regular basis. A laboratory can compare its results for each type of analysis with the range of results found for all participants (although the others are not named).

All standards define statistical variability but some Australian Standards are notable for their emphasis on it. They define repeatability (or precision) by specifying that duplicate analyses should agree within 0.15% absolute for moisture content, 0.15% for ash and 0.12MJ/kg for calorific value. Inter-laboratory reproducibility should be 0.3% for ash and 0.26MJ/kg for calorific value. (Not applicable for moisture analysis because it is considered too difficult to get agreement when sample moisture changes in transit.) However, in some laboratories these are considered to be too idealistic and the wider range US ASTM ones may be more practical.

Ultimate analysis

Ultimate analysis (mainly for carbon content) is relatively uncommon compared with proximate analysis and calorific value. Neither of the laboratories accredited for coal analysis in New Zealand (CRL Energy and SGS) offers a service to measure carbon. CRL Energy uses a carbon analysis instrument and is investigating the possibility of upgrading its in-house method to a prescribed standard.

Most carbon analyses in recent years have come through CRL Energy from ALS (formerly ACIRL) in Australia (using an accredited in-house method that is said to be equivalent to the Australian Standard AS 1038.6.4-2005 for instrumental carbon analysis). There are at least two other laboratory chains in Australia (SGS and Bureau Veritas) that are accredited for AS 1038.6.4-2005. The repeatability limits allow duplicates to differ by up to 0.3% carbon (dry basis). For inter-laboratory reproducibility, the difference can be 0.6%, although it is not clear whether this is determined as the difference from certified standard values or from round robin consensus values.

Twenty years ago, CRANZ (CRL Energy's predecessor) conducted a number of carbon analyses (Hennessy 1987) using high temperature combustion that is still the basis of an ISO method (ISO 609:1996). The method has a high level of precision but is too laborious to be cost effective for normal laboratory samples. This and the labour intensive Liebig method (see Appendix A) appear to be based on equivalent British Standards. There is also ISO 12902:2001 for instrumental methods.

The ASTM instrumental method allows repeatability of duplicates to be 0.64% carbon (dry basis) (vs 0.3% for the ASTM high temperature combustion method). For inter-laboratory reproducibility, the difference can be 2.5% (vs 0.6% for the high temperature combustion method). There is further discussion of inter-laboratory reproducibility in Appendix B.

Continuous emissions monitoring

Continuous emissions monitoring of flue gases is generally not justified for accurate measurement of CO_2 emissions only, because of the comparatively high cost (Adams 2008). However, it could be undertaken particularly when monitors are installed for the measurement of SO_2 or NO_x. Continuous emissions monitoring is useful for combustion of solid fuels where it is more difficult to measure fuel flow rates, or when fuels are highly variable, or fuel analysis is otherwise expensive. Continuous emissions monitoring requires attention to quality assurance and quality control, including certification of the monitoring system, re-certification after any changes, and assurance of continuous operation.

For CO_2 measurements, data from such systems can be compared with emissions estimates based on fuel flows. CRL Energy assesses that CO_2 emission factors for coal used in a large plant would be known to such a high degree of precision and accuracy that it would be a major challenge to prove that a continuous emissions monitoring system would achieve similar accuracy.

4. Average Mined Coal Properties

The Energy Data File (MED 2008a) records annual coal production, consumption, imports and exports for New Zealand. In 2007, 4,835,408 tonnes of coal were produced, of which 42% was bituminous coal, 53% was sub-bituminous and 5% lignite. Approximately 2.0 million tonnes of bituminous coal were exported and about 0.8 million tonnes of sub-bituminous coal imported.

Because of the wide range of heat content (calorific value) for the different coals, it is more useful to summarise coal consumption in terms of gross petajoules (PJ)[9]. For 2007, MED estimated that 26.9PJ was used at Huntly Power Station, 17.7PJ at NZ Steel, 17.2PJ for the industrial sector, 3.9PJ for the commercial sector and about 2PJ total for the agriculture, residential and transport sectors.

On the basis of a limited range of carbon analyses for run-of-mine coal samples, Table 3 sets out the average properties (and estimates of their variability) for each class of coal mined in New Zealand, weighted on 2008 coal production tonnages. It also contains the CO_2 emission factors (per tonne and per unit heat) calculated from these average properties (and estimates of their variability).

CAUTIONARY NOTE – The data in Table 3 and any conclusions drawn from it require an important cautionary note: the CO_2 emission factor relationship has not been checked for any New Zealand industrial coals currently mined. Compared with the last time this exercise was undertaken (Whitney and Hennessy 1990), large numbers of carbon analyses were made available from borehole samples for just four of the 23 currently active mines. There were also outcrop (face) sample analyses for 11 of those 23 mines but there are no carbon analyses of recent (last 10 years) coal samples that represent delivered industrial coals.

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[9] In 2007, average conversions for 1PJ were 63,090 tonnes lignite, or 44,740 t sub-bituminous, or 34,670 t bituminous produced for NZ use, or 31,620 t exported bituminous.

International evidence (IPCC 2006, Smith 1997) and evidence from NZ borehole analyses (Solid Energy 2008) suggest the CO_2 emission factor per unit heat is a remarkably consistent quantity within a coalfield so it can readily be used with the frequent analyses undertaken for gross calorific value of New Zealand industrial coals. Nevertheless, there are some large gaps in knowledge for some coalfields and some educated guess-work has been required to try and fill those gaps. In particular, this means there is limited information on the range and variability of emission factors but with the caution in mind, conclusions can still be drawn from this limited data range.

Table 3 – Average properties for classes of coal mined in New Zealand

	Lignite[#]	Sub-bituminous	Bituminous (produced for NZ use)	Bituminous (exported)
Moisture average (% as received)	42.1	21.9	10.0	9.5
Moisture range (% as received)	-	18.1 – 30.4	5.9 – 18.9	5.9 – 18.9
Moisture (% std devn/mean)	-	*13.1%*	*27.6%*	*35.3%*
Ash average (% as received)	3.1	4.5	2.7	3.5
Ash range (% as received)	-	2.8 – 8.3	1.6 – 5.1	2.1 – 8.0
Ash (% std devn/mean)	-	*21.9%*	*40.4%*	*48.9%*
Gross calorific value average (MJ/kg as received)	14.99	21.98	29.51	30.65
Gross calorific value range (MJ/kg as received)	-	18.90 – 24.20	23.93 – 31.65	25.00 – 31.95
Gross calorific value (% std devn/mean)	-	*5.6%*	*7.3%*	*6.7%*

	Lignite[#]	Sub-bituminous	Bituminous (produced for NZ use)	Bituminous (exported)
Carbon content average (% as received)	38.0	55.1	71.6	75.3
Carbon content range (% as received)	-	46.9 – 59.9	59.2 – 76.4	72.2 – 76.6
Carbon content (% std devn/mean)	-	*5.7%*	*6.7%*	*1.8%*
Tonnes CO_2 per tonne coal average	1.40	2.02	2.63	2.77
Tonnes CO_2 per tonne coal range	-	1.72 – 2.20	2.17 – 2.80	2.65 – 2.80
Tonnes CO_2 per tonne coal (% std devn/mean)	-	*5.7%*	*6.7%*	*1.8%*
CO_2 emission factor average (tCO_2/TJ*)	93.1	92.0	89.1	88.2
CO_2 emission factor range (tCO_2/TJ)	-	90.8 – 92.2	88.0 – 90.8	88.0 – 90.8
CO_2 emission factor (% std devn/mean)	-	*0.42%*	*1.30%*	*0.49%*

There are only two active mines in separate lignite coalfields so there is insufficient variability information to be meaningful for this table.

* tonnes of CO_2 per terajoule of gross energy contained in the coal (or $kgCO_2$/GJ or gCO_2/MJ) assuming 100% oxidation

The coefficients of variation (estimates of standard deviations/mean) are relatively high for calorific values and for carbon contents (and the tCO_2/t coal emission factors derived from the latter) because of the variability of ash and particularly moisture content. However, the relatively low coefficients of variation for the tCO_2/TJ emission factors demonstrate how useful this measure is (because the moisture and ash variabilities are removed).

The cautionary note needs to be spelt out in some detail here because the range of emission factors may prove to be somewhat wider in future when some unique emission factors are developed for representative samples of delivered industrial coals.

1. The two estimated lignite mine emission factors (93.1 and 91.5 tCO_2/TJ) were based on five and two face sample analyses respectively[10].

2. Of the eleven active sub-bituminous coal mines in 2008, six emission factor estimates were based on face sample and a few borehole analyses. Four of the other five were based on estimates that would be classed as highly uncertain because there are no carbon analyses available from those coalfields.

3. Of the ten active bituminous coal mines in 2008, three emission factor estimates were based on extensive borehole analyses helpfully made available by Solid Energy. Two others were based on a few face samples and the remaining five (including two medium scale mines[11]) were based on estimates that would be classed as highly uncertain because there are no carbon analyses available from those coalfields.

Given these potential sources of bias, estimating uncertainties is a matter of expert judgement of accuracy rather than a numerical exercise to combine precision estimates. CRL Energy assesses that if there were precise measurements of appropriate samples from each of the 2008 coal mines, the average CO_2 emission factor results ("true means") would be 95% likely to lie within:

- ± 1.5% of the current lignite estimate,
- ± 0.7% of the current sub-bituminous estimate and
- ± 1.0% of the current bituminous estimate.

Comparison with international values

The estimated emission factor ranges for these coals fall well within the very broad IPCC (2006) ranges: 86.4 to 109.2 tCO_2/TJ for lignites, 88.2 to 95.0 for sub-bituminous coals and 82.9 to 96.0 for bituminous and coking coals[12]. With such wide ranges, the IPCC averages may be meaningless for New Zealand comparison: 96.0 tCO_2/TJ for lignites, 91.3 for sub-bituminous coals and 89.9 for bituminous and coking coals. The NZ sub-bituminous (92.0) and bituminous (89.1 and 88.2) averages are surprisingly similar but the lower lignite figure (93.1) suggests that New Zealand lignites currently mined are somewhat higher rank than the majority of lignites or brown coals mined around the world.

For comparison, Smith (1997) noted that national weighted average CO_2 emission factors (on a gross or higher heating value basis) for USA coals in 1990 were 92.5, 91.4 and 88.1 tCO_2/TJ for lignites, sub-bituminous and bituminous coals respectively – very similar to the NZ figures. In contrast, gross emission factors for the range of brown coals used in seven European countries in 1992 were significantly higher: 100 to 117 tCO_2/TJ while the range for

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[10] A few samples from the two main lignite fields (Waimumu and Mataura) actively mined in 1988 indicated emission factors around 93.8 tCO_2/TJ (Whitney and Hennessy 1990). It is unclear how Baines (1993) derived a 95.2 figure for average lignite from this data.

[11] 40,000 to 100,000 tonnes range

[12] After conversion from the net emission factors used by the IPCC (multiplying by 0.95) to the gross emission factors used in New Zealand.

hard coals (sub-bituminous and bituminous) in nine European countries was 87.9 to 91.3 tCO_2/TJ.

For a more recent comparison, Herold (2003) showed that eight out of 14 EU member states (and four out of eight accession countries) reported at least some country specific emission factors for certain solid fuel types in their 2002 and 2003 national inventory reports. (The others used IPCC defaults for all types.) For lignites, eight of the 22 states used country specific gross emission factors ranging from 94 to 118 tCO_2/TJ, 90 to 95 for three states using sub-bituminous coals, 82 to 95 for eight states using bituminous coals and 83 to 92 for six states using coking coals. Looking at some of the patterns (ignoring some probable reporting errors), CRL Energy assesses that some of these countries clearly had problems with their coal rank classifications and perhaps problems with their data and reporting quality.

In contrast with this high degree of variability, a recent compilation of 1400 Indian coal analyses showed a reasonably consistent range of gross CO_2 emission factors despite a wide range of coal properties (Roy and others 2009). For 180 coking coals[13], most ranged from 88 to 92 (with a few up to 94) and there was no apparent correlation with some very high ash content coals (entire range from 9% to 36% air dried basis). For 1214 non-coking coals, most ranged from 88 to 96 (with a few as wide as 85 to 98) and again there was no apparent correlation with some very high ash content coals (entire range from 16% to 41% air dried basis).

Australia's national greenhouse and energy reporting guidelines (ADCC 2008) use the following default values for gross CO_2 emission factors (before oxidation factors are applied):

- 93.6 tCO_2/TJ for brown coal,
- 90.1 for black coal (bituminous and sub-bituminous other than that used to produce coke),
- 92.0 for coking coal (based on somewhat contradictory figures).

5. Average Imported Coal Properties

Genesis Energy and Golden Bay Cement have imported a small range of coals for several years. These imports should not be considered typical of the wide range of coals that could be imported in the future. The Energy Data File (MED 2008a) records that 5 to 10,000 tonnes of coal were imported each year from 1989 to 1997, then quantities steadily increased to 120,000t in 2002, 460,000t in 2003, 920,000t in 2004, 1,120,000t in 2005, 1,270,000t in 2006 and 770,000t in 2007. MED uses the Statistics NZ quarterly survey of imports and this is likely to fully cover the coal sector. CRL Energy does not know of any other sources of imported coal shipments but our staff would only hear of them "through the grapevine".

Contracts for imported coal shipments normally include the requirement for sampling and proximate analysis by an accredited laboratory according to specified standards. They may also include ultimate (carbon) analysis. Such analytical records would provide appropriate assurance for establishing unique emission factors.

Genesis Energy has imported a range of sub-bituminous coals from Indonesia for several years. Because the station was designed for using New Zealand sub-bituminous coals (as well as natural gas), imported coal specifications have been fairly similar to those of Waikato

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[13] Coking coals defined as carbon content between 84% and 92% dry mineral matter free vs non-coking coals between 74% and 84%. Most NZ sub-bituminous and bituminous coals (no lignites) would fall into this non-coking category with only a few of the high swelling coals falling into the coking category.

coals. The company kindly provided a summary of analytical reports for several coal shipments in 2005 representing three different coals. The summary of analyses is commercially sensitive but the CO_2 emission factors may be commented on because they are typical of sub-bituminous coals in general.

The analyses show the properties of two of the coals are remarkably consistent over the large numbers of shipments in 2005 (there was only one shipment of the third coal). The coefficient of variation (standard deviation/mean) for Coal A moisture content was just 2.2% (2.6% for Coal B) and only 1.1% for as received gross calorific value (2.3% for Coal B). For 16 of the Coal A shipments, the coefficient of variation for the emission factor per unit weight (1.98 tonnes CO_2/ tonne coal) was 1.1% while the same for the emission factor per unit heat (91.8 tonnes CO_2/TJ) was 0.7%. For 11 of the Coal B shipments, the coefficient of variation for the emission factor per unit weight (1.87 tonnes CO_2/ tonne coal) was 1.7% while the same for the emission factor per unit heat (93.2 tonnes CO_2/TJ) was 1.0%.

Both sets of coal properties demonstrate that the emission factor per unit heat has a lower level of variability because the moisture and ash variability components are removed. The 91.8, 93.2 (and 91.2 for the single Coal C shipment) tCO_2/TJ figures are similar to the range of sub-bituminous coal emission factors for New Zealand coals and well within the IPCC (2006) range (88.2 to 95.0) for sub-bituminous coals.

The variabilities of these measured properties should not be taken as typical of all imported coal shipments. They represent a remarkably consistent series of shipments that might change significantly if Genesis Energy changes its imported coal supplier in future.

Golden Bay Cement has imported bituminous coal from New South Wales from the start of 2002 (Bourke 2009). The company kindly provided analytical reports from a NATA accredited laboratory for three recent shipments. Cement kiln operators place a high value on consistency of heating and mineral properties in their fuel and this is evident in the low variability of these properties in the three shipments. The range of total moisture analyses was just 0.5%, ash content (as received basis) ranged from 11.6 to 14.7% while calorific value ranged from 26.51 to 27.34 MJ/kg. On a dry mineral matter free basis, the calorific value range narrowed to 34.96 to 35.25 MJ/kg.

Two of the analytical reports also included ultimate analyses showing 83.4% and 86.0% carbon (dry mineral matter free basis). These figures translated to CO_2 emission factors of 87.5 and 89.6 tCO_2/TJ. Further information would be useful to assess this apparently high degree of variability. However, there appears to be no significant difference from the 88.4 figure reported for the average New Zealand high volatile A bituminous coal (Whitney and Hennessy 1990).

The variabilities of these measured properties should not be taken as typical of imported coal shipments. They represent a fairly consistent series of three shipments that might change significantly if Golden Bay Cement changes its coal supplier in future.

In future, it is recommended that MED calculate a weighted average calorific value for imported coal for the Energy Data File calculations. On the basis of import tonnage information provided by Statistics NZ, CRL Energy estimates that the weighted average calorific value for imported bituminous and sub-bituminous coal for 2008 was 21.88 MJ/kg[14]. This is very close to the calculated weighted average calorific value of 21.98 MJ/kg for New Zealand sub-bituminous coal production in 2008 but somewhat lower than the 2007 average of 22.27 MJ/kg (Table 2). It therefore appears likely that imported coal energy quantities (and therefore eventual CO_2 emissions) have been over-estimated to a small degree from perhaps 2002 to 2007. Correction factors will be able to be estimated.

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[14] Omitting small quantities (up to 1000t each) of imported lignite and peat and several thousand tonnes of imported coke.

6. Combustion Methane and Nitrous Oxide Emissions

For the national greenhouse gas inventory, MED estimates the minor methane and nitrous oxide emissions resulting from combustion of coal and other fuels.

Formation of nitrous oxide is minimised when combustion temperatures are kept high (above 860°C) and excess air is kept to a minimum (<1%). Nitrous oxide emissions from coal combustion are not significant except for fluidised bed combustion where the emissions are typically about 100 times higher than all other types of coal firing due to areas of low temperature combustion in the fuel bed. Methane emissions vary with the type of coal being fired and the firing configuration, but are highest during periods of incomplete combustion, such as the start-up or shut-down cycle for coal fired boilers. Typically, conditions that favour nitrous oxide formation also favour emissions of methane (Adams 2008).

MED (2008b) has used IPCC (1996) default values (corrected to gross calorific value basis) for its combustion methane and nitrous oxide inventory estimates. Because there is no specific data for NZ boilers or kilns, these should be the appropriate values for calculation of default values[15]. However, there is an important contradiction in the IPCC (1996) treatment of Tier 1 methane estimates (based on national fuel use) and Tier 2 estimates (based on fuel use broken down to technology types). This has not been resolved in IPCC (2006) which repeats the general Tier 1 and usefully detailed Tier 2 tables for methane estimates, but with some significant reductions in nitrous oxide estimates.

It is unclear how some of the default emission factors were derived as detailed in MfE (2008). No justification is given why the default methane component for combustion of mined sub-bituminous and bituminous coals (and anthracite) has been set over three times higher than the appropriate IPCC (2006) default factor of 0.95 tonne methane per petajoule (or 0.67 for Huntly Power Station). Even more curiously, the same factor for lignite is over twenty times higher. Imported coals have been given the same treatment except that coking coal has been given the 0.67 factor for Huntly Power Station (which does not use coking coal).

Table 1-7 in IPCC (1996) noted that methane emissions for brown coal may be several times higher than for hard coal but there is no evidence of this in a review of coal emission factors (Smith 1997). One study showed there was no variation in the methane emission factors with the different coals, only with technology. She noted that the European agency assumed the same factor for hard and brown coal fired power stations and the same was true in Australia.

Smith (1997) stated that the IPCC Tier 1 default methane factors (10 t/PJ for most industrial and commercial boilers) were based on a 1993 study while the Tier 2 ones (1 t/PJ for most industrial and commercial boilers) were based on a more detailed USEPA study in 1995.

No review of more recent data has been found but Australia's national greenhouse and energy reporting guidelines (ADCC 2008) use the following default values for gross methane emission factors: 0.5 tCH_4/PJ for brown coal, 1.4 for black coal and 1.0 for coking coal.

It is clear there is no justification for treating hard and brown coals differently with regard to methane emission factors at the power station level and no evidence has been found for such treatment in industrial and commercial boilers where the vast majority of New Zealand lignite is used. CRL Energy considers there is no justification for inventory or ETS purposes in departing from the IPCC default Tier 2 factors. MED (2008b) has presumably estimated for inventory purposes the proportionally high methane emissions from residential coal use, but it would be difficult to justify spreading these emissions (from less than 1% of coal usage) over all coal sectors for ETS purposes.

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[15] One minor correction should be to treat industrial coal as the IPCC (1996) Table 1-16 overfeed or spreader stoker category (rather than the pulverised coal boiler) with a small increase in methane factor and an unchanged nitrous oxide factor.

In contrast with the methane methodology, the ETS default nitrous oxide components for combustion of mined and imported coals (MfE 2008) appear to be an average of the IPCC (1996) default factors for Tier 1 and Tier 2 industrial boilers. IPCC (2006) has reduced its nitrous oxide emission factors for coal combustion (presumably based on a review of recent information), so CRL Energy recommends the adoption of these lower Tier 2 emission factors: 0.48 tN_2O/PJ for power generation and 0.67 for most industrial and commercial boilers. There are no likely coal combustion sources of relatively high nitrous oxide emissions in New Zealand.

Combustion methane and nitrous oxide measurement

After requesting the Energy Library to search various measurement standard websites, there appears to be a lack of standards for measurement of combustion methane or nitrous oxide. The USEPA methods for measuring flue gas concentrations would be the most likely basis for developing such measurements to sufficient accuracy to be meaningful for this purpose. As a prerequisite, Methods USEPA 1 (sample and velocity traverses for stationary sources) and USEPA 2 (determination of stack gas velocity and volumetric flow rate) or ISO 10780 (measurement of velocity and volume flow rate of gas streams in ducts) would be necessary to demonstrate adequate sampling. Method 3C (determination of carbon dioxide, methane, nitrogen, and oxygen from stationary sources) could be used to measure methane by gas chromatography. Method 7 (determination of nitrogen oxide emissions from stationary sources) does not mention nitrous oxide but there are methods in the scientific literature for automated gas chromatography, one claiming a practical detection limit of 0.1 part per million.

K2 Environmental (2009) offers a service using this method which claims to obtain a detection limit of 1 ppm for methane and 0.1% (1000ppm) for nitrous oxide. The company could purchase for about $150,000 an infrared detection instrument that would provide greater accuracy and precision for much lower concentrations but it is considered unlikely that clients would be prepared to pay for such an expensive service.

7. Calculation of CO_2 Equivalent Emission Factors

The Ministry for the Environment's Emission Trading Group has published its methodology for calculating CO_2 equivalent emission factors for the draft ETS regulations (MfE 2008). For mined coal, the CO_2 components for lignite, sub-bituminous and bituminous coals [16] are based on the Baines (1993) values as the most recent compilation available in 2008. It would be appropriate to replace them with the average values derived in this report and review them once more information becomes available through the development of unique emission factors for different coalfields.

For imported coals, the CO_2 components have been set at levels 15%, 4% and 7% higher than the mined coal values for lignite, sub-bituminous and bituminous coals. No justification is evident but presumably they have been proposed as conservatively high values until better information is available. It is unlikely that it would ever be cost effective to import large quantities of lignite but the IPCC default value of 96.0 tCO_2/TJ would be more appropriate. As discussed earlier, the typical analysis for an imported coal shipment (if it includes carbon analysis) should provide adequate documentation for establishing a unique emission factor for imported sub-bituminous and bituminous coals.

To derive the CO_2 equivalent emission factor, the CO_2 component is multiplied by the IPCC default oxidation factor and added to the combustion methane and nitrous oxide components

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[16] No justification is evident for setting the CO_2 component for coking coal and anthracite (though the latter is not relevant in NZ) 6.8% and 2.7% respectively higher than the IPCC default values.

(IPCC default values discussed above, multiplied by 21 and 310 as their respective 100 year Global Warming Potentials[17]).

Oxidation factor

IPCC (1996) stated that a small amount of carbon in each type of fuel and some of that carbon remains unoxidised and is assumed to be stored indefinitely (primarily in the ash in the case of coal). It referred to Australian observations of about 1% unoxidised in power stations and 1% to 12% in stoker fired industrial boilers and British Coal information ranging from 1.6% to 6.6%. IPCC recommended a default assumption of 2% (0.98 oxidation factor) and this has been used for the draft ETS regulations (MfE 2008)[18].

No review of more recent data has been found. CRL Energy has calculated that Australia's national greenhouse and energy reporting guidelines (ADCC 2008) use the following oxidation factors for their default CO_2 equivalent emission factors: 2.1-2.2% for black and coking coal and 0.9% for brown coal.

It is difficult to estimate an oxidation factor that can adequately cover a range of technologies and firing conditions that include highly efficient combustion through to reduced efficiency boiler conditions. In the absence of New Zealand specific information, the 0.98 oxidation factor appears to provide an adequate estimate.

Using the average CO_2 emission factors from Table 3 and the IPCC (2006) default factors for oxidation, combustion methane and nitrous oxide for industrial coal use would give the CO_2 equivalent emission factors in Table 4.

Table 4 – Derivation of CO_2 equivalent emission factors

	Lignite	Sub-bituminous	Bituminous (produced for NZ use)	Anthracite
CO_2 EF (tCO_2/TJ)	93.11	91.99	89.13	93.39
Oxidation factor	0.98	0.98	0.98	0.98
Combustion CH_4 EF (tCO_2e/TJ)	0.02	0.02	0.02	0.02
Combustion N_2O EF (tCO_2e/TJ)	0.21	0.21	0.21	0.21
Total CO_2 equivalent EF (tCO_2e/TJ)	*91.47*	*90.38*	*87.57*	*91.74*

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[17] These GWPs have been revised in the scientific literature but for accounting purposes they are currently kept at the levels agreed when the Kyoto Protocol was developed.

[18] There is some confusion in IPCC (2006) where an oxidation factor of 1 is used for a Tier 1 approach but it is acknowledged that this effect is "neglected" and for "some solid fuels, this fraction will not necessarily be negligible, and higher Tier estimates can be applied". Since the Tier 2 approach is used where possible for the other CO_2 equivalent factor components, the 0.98 default oxidation factor is still appropriate.

These calculations show four significant figures for the purpose of the derivation but whatever default emission factors are finalised, they should be rounded off to three significant figures (rather than imply a high degree of accuracy with more figures).

8. Procedure for Establishing Unique Emission Factors

Under the ETS regulations being developed, coal miner, importer and opt-in participants will be able to apply for unique emission factors (UEFs). The purpose of this section is to outline some of the issues officials will face in deciding some of the requirements for this UEF application procedure with regard to different classes of coal or coal field.

Fugitive coal seam gas UEFs would be much more complex and the issues are outlined in the next section.

CRL Energy recommends that the over-riding requirement for this UEF application procedure should be that it is considered of equivalent (not greater) importance to the sampling and analytical requirements on which coal customers contract to pay their suppliers.

As discussed in earlier sections of this report, large imported or exported coal shipments (25,000 tonnes or more) have strict requirements for coal sampling, preparation and analysis that are the basis of payment to coal suppliers. A coal customer using several thousand tonnes of coal annually would also be likely to require regular sampling and testing, especially where coal quality is an important issue for boiler maintenance or process control.

At the lower extreme, truckloads of coal (20 to 30 tonnes) would not have individual analyses but payment to the supplier would instead be based on the weighbridge tonnage and perhaps a monthly (or quarterly depending on mine size) analysis of as received calorific value (and other properties). Since this is the basis of customers paying for their fuel, it should also be the basis for the coal producers' records to determine their emissions obligations. From their weighbridge totals, coal blend proportions and regular calorific value analyses, the coal supplier will have to calculate the emissions obligation using the default emissions factors on an ongoing basis in order to recover those costs from their customers.

If a coal producer (or importer or opt-in participant) wishes to apply for a UEF for a particular class of coal, the following sampling, preparation and analytical requirements would be reasonable:

A) Evidence that a representative sample of the coal was obtained and prepared by an organisation accredited for sampling and preparation according to ISO 18283:2006 (or equivalent in the view of International Accreditation New Zealand or by an overseas accreditation agency recognised under New Zealand's mutual recognition arrangements)[19].

B) Analytical results for the following properties of the coal that have been carried out according to stated methods (see options below) by a laboratory accredited (by IANZ or equivalent) to carry out those tests according to ISO 17025:

1. moisture content (as received basis)

2. ash content (as received basis)

3. sulphur content (as received basis)

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[19] ISO 18283:2006 is for sampling and preparation of hard coal but the principles are the same for brown coal or lignite.

4. gross calorific value (as received basis)
5. carbon content (as received basis)[20]

All of these quantities are measured on an air dried basis and then calculated by the laboratory to an as received basis or dry basis or dry ash free basis. If say the carbon content is measured on a different day from the other measurements, it is standard practice to re-measure the moisture content on that day to correct for any small changes.

The CO_2 emission factor for the coal is calculated using the following formula:

CO_2 emission factor (tonnes CO_2 per terajoule)

= carbon% (as received basis) x 36.7/gross calorific value (MJ/kg as received basis)

Ash and sulphur content are not directly used in the formula to calculate the CO_2 emission factor but they represent important information for a verifier to assess whether a coal sample is typical of a particular coalfield. For some New Zealand coals, high sulphur content is associated with lower CO_2 emission factors and higher ash samples can be associated with high emission factor variability.

The unique emissions factor (tonnes CO_2 equivalent per terajoule) for the class of coal is then calculated using the following formula:

UEF (tCO_2e/TJ) = $EFCO_2$ x 0.98 (oxidation factor) + $EFCH_4$ + EFN_2O

where $EFCH_4$ and EFN_2O are the emission factors for methane and nitrous oxide emitted during combustion of the coal.

The options for regulations setting are to allow analytical tests where:

1. the laboratory claims to follow an established standard (ISO, Australia/New Zealand, ASTM, BS or equivalent); or
2. the laboratory claims to follow an established standard or in-house method; or
3. the laboratory is accredited for following an established standard only; or
4. the laboratory is accredited for following an established standard or in-house method where evidence is provided of good performance for each test method in regular round robin inter-laboratory coal testing.

In CRL Energy's experience, non-accredited lab results may be quite adequate for quality control for many coal users monitoring their fuel quality. However, when the lab results may be used for contract pricing and possible penalties for not meeting specifications, accredited lab results from established standard methods are necessary (option 3).

Laboratory accreditation provides only limited assurance of continuing good quality management of analytical procedures. Regular participation in round robin inter-laboratory coal testing is the best way of providing ongoing quality assurance. Consequently, the provision of such evidence of good performance for a non-standard, in-house method may be

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[20] Carbon or ultimate analysis is usually reported on a dry coal basis. To correct to the as received basis, use the formula:
C (as received) = C (dry basis) x (1 – moisture% as received/100)

considered adequate justification of its use for establishing a unique emission factor (option 4). For example, the ALS (Ipswich) lab established its instrumental carbon in-house method long before the Australian Standard was developed and this in-house method has been accredited by NATA. ALS provided CRL Energy with evidence of several round robin carbon analyses that showed results consistent with inter-laboratory reproducibility limits over several years.

It is not appropriate for CRL Energy to advise on how frequently a UEF should be confirmed or whether there should be some threshold for differences between the UEF and the default emission factor. However, the provision of variability information for the range of coalfields and for coal tests should assist officials to make any such decisions.

9. Fugitive Coal Seam Methane

Methane is the most important fugitive greenhouse gas emission from coal mining. Methane gas naturally entrained in the pores of coal seams is desorbed (released) into the atmosphere from exposed coal faces or fissures. The volume entrained in coal varies directly with increasing coal rank and seam depth, among other factors. Coal seam properties such as porosity and permeability will influence the rate of desorption and the extent to which desorption occurs when the seam is exposed. Methane is a potential hazard and so there are systems for ventilating mines and in some cases, degasifying or draining the gas ahead of the mining.

Fugitive emissions from underground mining arise from both ventilation and degasification systems, and can be considered as point sources. For surface mining, emissions are generally dispersed over sections of the mine and are best considered area sources. The emissions may be the result of seam gases emitted through the processes of breakage of the coal and overburden, low temperature oxidation of waste coal or low quality coal in dumps, and uncontrolled combustion. Measurement methods for low temperature oxidation and uncontrolled combustion are still being developed and so are not included in IPCC (2006) methodology (Adams 2008).

For Tier 1 (nationwide estimate) and Tier 2 (specific mine estimate) approaches, the emission factor for underground, surface and post-mining emissions has units of cubic metres per tonne of raw coal mined, the same units as in situ gas content[21]. The emission factor is always larger than the in situ gas content because the gas released during mining draws from a larger volume of coal and adjacent gas-bearing strata than simply the volume of coal produced (Adams 2008).

Mine-specific data, based on ventilation air and degasification system measurements, reflect actual emissions on an individual mine basis, and so provide a more accurate estimate than using emission factors (Adams 2008).

For the ETS draft regulations (MfE 2008), the IPCC (2006) low, average and high methane emission factors (including post-mining) appear to have been used as the basis of estimates for underground mines at depths of <200m, 200-400m and >400m respectively. The MfE factors are respectively 115%, 100% and 95% of the IPCC factors, although no evidence is presented for these choices.

For surface mining, again there is no evidence presented for the draft ETS choices of methane emission factors (including post-mining) equivalent to 133% of the IPCC low factor for overburden depth <25m, 100% of the average factor for overburden depth 25-50m and 95% of the high factor for overburden depth >50m.

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[21] In situ gas content is measured on a borehole sample as the amount of gas desorbed over a standard period. It may be a mixture of methane and CO_2 so the proportions need to be measured.

For comparison, Australia’s national greenhouse and energy reporting guidelines (ADCC 2008) use for underground “gassy” mines a default CO_2 equivalent emission factor (including post-mining) of 111% of the average IPCC (2006) factor. “Non-gassy” mines have a default factor of just 5% of the low IPCC factor.

IPCC (2006) continues to highlight the huge natural variability of methane emissions and consequent large uncertainties for the emission factor estimates. It is estimated that for a Tier 1 country wide approach for underground mining methane the uncertainties range from 50% to 200% of the mean estimate (33% to 300% of the post-mining emissions). For a Tier 2 basin specific approach, the uncertainties reduce to ± 50-75% (and ± 50% for post-mining). For surface mining, the Tier 1 approach uncertainties range from 33% to 300% of the mean estimate while the Tier 2 approach is expected to reduce these uncertainties to 50% to 200% of the mean.

These uncertainties and the measurement difficulties have been the main reasons for strong opposition from the New Zealand coal industry to inclusion of fugitive coal mining methane being included in the ETS coverage. These and other arguments from the Solid Energy (2008) ETS submission are summarised here.

- In some of the major coal producing provinces of the world (North America, parts of Europe and Australia) seams have relatively consistent properties so the IPCC has established nominal methane emission factors for opencast and underground mining by coal rank.

- New Zealand (as well as Japan, Indonesia and other countries) have active tectonic plate boundaries beneath the coalfields and intensive faulting has produced anomalous high rank coals at shallow depths. Coal seams in New Zealand are often highly fissured and extremely variable in many properties over short distances.

- Assessing realistic averages for default emission factors and establishing a cost effective methodology to determine reliable unique emission factors would require substantial research on the variability of seam properties and the consequent requirement for borehole sampling standardisation and frequency.

- This would give a means of assessing variability of seam properties but there are many other key factors influencing the release of methane from underground and opencast coal (particularly the underground extraction percentage representing coal faces that are exposed but left in place). There would be measurement standardisation, sampling frequency and safety issues to be resolved if ventilation monitoring was to be used for determining the liability for underground mines.

- The desorption rate of the methane remaining in the mined coal depends on a number of factors, in particular the production size split and storage conditions. This is an important factor needing research and a cost effective assessment methodology because any methane left entrained in coal when it is combusted in a boiler would be converted to CO_2.

- There are some liability and equity issues to be resolved (perhaps in court) because Crown Minerals is of the view that methane falls within the petroleum minerals regime – sometimes the coal miner does not own the rights to the methane.

Measurement and sampling issues

Although of limited use in predicting mine emissions, there are three methods in common use in New Zealand for determination of gas content of coal samples. A US Geological Survey method is most commonly used because it is considered most useful for resource evaluation and a proprietary method is occasionally used. The Australian Standard AS 3980-1999

(Guide to the determination of gas content of coal - Direct desorption method) is likely to be quicker than the USGS method and so less expensive than the ~$750 per sample currently charged, according to CRL Energy geologists offering this service. To attempt to predict mine emissions, they explain that a reservoir assessment (including issues such as mine design and coal permeability) would be required, costing in the order of ~$5000.

In order to measure methane in underground mine ventilation air, standard methods are required to accurately measure the methane concentration (and frequently to understand the variability) and the associated mine ventilation rate. The only method that could be found is probably not appropriate since it is more safety oriented rather than for accounting purposes: AS/NZS 60079.29.1:2008 (Explosive atmospheres - Gas detectors - Performance requirements of detectors for flammable gases).

10. Quality Assurance

The details of calculations of average mined coal properties were described in Chapter 4. Weighted averages were based on coal mine output figures for 2008 supplied by Crown Minerals. All data entry figures were checked for transposing errors and a number of check calculations were performed to minimise the potential for errors in some of the more complicated cell formulae. As a further check, some of these calculations were independently checked by Dr Murray McCurdy of CRL Energy.

Provisos have been stated about the inadequacy of some data but we have concluded that in spite of these inadequacies, average emission factors (and other coal properties) are likely to be reasonably accurate.

To repeat our expert judgement of accuracy from Chapter 4, CRL Energy assesses that if there were precise measurements of appropriate samples from each of the 2008 coal mines, the average CO_2 emission factor results (“true means”) would be 95% likely to lie within:

- ± 1.5% of the current lignite estimate,
- ± 0.7% of the current sub-bituminous estimate and
- ± 1.0% of the current bituminous estimate.

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Appendix A – Standards for Sampling and Measurement

CRL Energy has prepared this near-comprehensive list of ISO, US ASTM and Australian AS standards that are likely to provide equivalent assurance of coal sampling, preparation and analysis procedures relevant to this report. Inter-laboratory reproducibility would be a much more significant source of variability than any differences among these standards.

Without reviewing any differences in detail, CRL Energy considers any of the following standards (among others) would give assurance of adequate coal sampling and preparation for contractual purposes:

ISO 13909:2001 Hard coal and coke - Mechanical sampling - Parts 1 to 8

ISO 18283:2006 Hard coal and coke - Manual sampling

ISO 5069-1:1983 Brown coals and lignites - Principles of sampling - Part 1: Sampling for determination of moisture content and for general analysis

ISO 5069-2:1983 Brown coals and lignites - Principles of sampling - Part 2: Sample preparation for determination of moisture content and for general analysis

ASTM D2013 Method of preparing coal samples for analysis

AS 4264.1-1995 and (for brown coal) AS 4264.3-1996.

Without reviewing any differences in detail, CRL Energy considers any of the following standards (among others, including earlier versions) would give assurance of adequate measurement of coal properties for contractual purposes:

ISO 5068-1:2007 Brown coals and lignites – Determination of moisture content - Part 1: Indirect gravimetric method for total moisture.

ASTM D3302 Test method for total moisture in coal.

ISO 5068-2:2007 Brown coals and lignites – Determination of moisture content - Part 2: Indirect gravimetric method for moisture in the analysis sample.

ISO 11722:1999 Solid mineral fuels - Hard coal - Determination of moisture in the general analysis test sample by drying in nitrogen.

ASTM D3173-03 Method for moisture in the analysis sample of coal and coke.

AS 1038.1-2001, AS 1038.3-2000 and (for brown coal) AS 2434.1-1999 for moisture content.

ISO 1171:1997 Solid mineral fuels - Determination of ash.

ASTM D3174-04 Method for ash in the analysis sample of coal and coke.

AS 1038.3-2000 and (for brown coal) AS 2434.8-2002 for ash content.

ISO 17246:2005 Coal - Proximate analysis (incorporating specific ISO moisture and ash standards above).

ASTM D3172-89 (2002) Proximate analysis of coal and coke (incorporating specific ASTM moisture and ash standards above).

ASTM D5142 Proximate analysis of the analysis sample of coal and coke by instrumental procedures.

ISO 1928:1995 Solid mineral fuels - Determination of gross calorific value by the bomb calorimetric method, and calculation of net calorific value.

ASTM D5865-07a Gross calorific value of coal and coke.

AS 1038.5-1998 for calorific value (black and brown coal).

ISO 609:1996 Solid mineral fuels - Determination of carbon and hydrogen - High temperature combustion method.

ISO 625:1996 Solid mineral fuels - Determination of carbon and hydrogen - Liebig method.

ISO 12902:2001 Solid mineral fuels - Determination of total carbon, hydrogen and nitrogen - Instrumental methods.

ISO 17247:2005 Coal - ultimate analysis (incorporating methods above).

ASTM D3178-02 Carbon and hydrogen in the analysis sample of coal and coke.

ASTM D5373-02 Instrumental determination of carbon, hydrogen and nitrogen in laboratory samples of coal and coke.

ASTM D3176 Practice for ultimate analysis of coal and coke (incorporating methods above).

AS 1038.6.1-1997 (high temperature combustion), AS 1038.6.4-2005 (instrumental) and (for brown coal) AS 2434.6-2002 for carbon content.

ISO 334:1992 Solid mineral fuels - Determination of total sulfur - Eschka method.

ISO 351:1996 Solid mineral fuels - Determination of total sulfur - High temperature combustion method.

ASTM D4239-08 Sulfur in the analysis sample of coal and coke using high-temperature tube furnace combustion methods.

AS 1038 Part 6.3.3 - Total sulfur.

Appendix B – Inter-laboratory Reproducibility

CRL Energy has participated in a number of international round robin analyses over the years as a useful monitor of inter-laboratory reproducibility. For understanding measurement variability, it is instructive to consider a summary of the findings of one of the larger studies.

Over the last two years, approximately 120 laboratories (mainly in North America) measured the as received moisture content of eight coals (ranging 1% to 20% moisture). The distribution of results demonstrated fairly high coefficients of variation ranging from 2% relative (for higher moisture coals) to 5% (for lower moisture coals) and 15% and 19% for two very low moisture coals. Typically 5 to 15 of the laboratories' results were rejected because they lay outside 3 standard deviations of the consensus mean. It should be noted that inter-laboratory reproducibility studies of moisture content are particularly error-prone because of the difficulties of moisture changes during sample dispatch.

Approximately 120 laboratories measured the ash content (dry basis) of eight coals (ranging 5% to 8% ash). The distribution of results demonstrated fairly low coefficients of variation ranging from 0.9% to 2.1% relative (with one at 3.0%). Typically 1 to 7 of the laboratories' results were rejected because they lay outside 3 standard deviations of the consensus mean.

Approximately 110 laboratories measured the calorific value (dry basis) of eight coals (ranging 27 to 34 MJ/kg). The distribution of results demonstrated very low coefficients of variation ranging from 0.2% to 0.5% relative (with one at 0.7%). Typically 3 to 5 of the laboratories' results were rejected because they lay outside 3 standard deviations of the consensus mean. For five of the coals, the testing organisation showed that the measured heating value was between only 0.1% and 0.6% different from the theoretical value calculated from highly accurate measurements of the elemental composition, a surprising confirmation of the calorific value method accuracy.

Approximately 54 laboratories measured the carbon content (dry basis) of eight coals (ranging 69% to 85% carbon). The distribution of results demonstrated fairly low coefficients of variation ranging from 0.8% to 1.3% relative. Typically 1 to 6 of the laboratories' results were rejected because they lay outside 3 standard deviations of the consensus mean. For all analyses, if a laboratory's result is outside 2 standard deviations of the consensus mean, they are asked to review their analytical procedure. Typically, two thirds of the laboratories used the ASTM instrumental method, about six used unstated in-house methods, and about five used high temperature combustion methods.

Judging from the variability of these carbon results, for a typical New Zealand sub-bituminous coal (70% carbon dry basis), this testing organisation would not reject results between approximately 68% and 72% carbon. This confirms the comment in Chapter 3 that the ASTM reproducibility difference of 2.5% for the instrumental method is more typical of current laboratory practice than the more stringent 0.6% specified for the high temperature combustion method. This level of variability (about 3% relative) should consequently be considered typical for the CO_2 emission factor too (since the variability of the calorific value component should be minimal by comparison). A well calibrated method should be able to achieve significantly better.