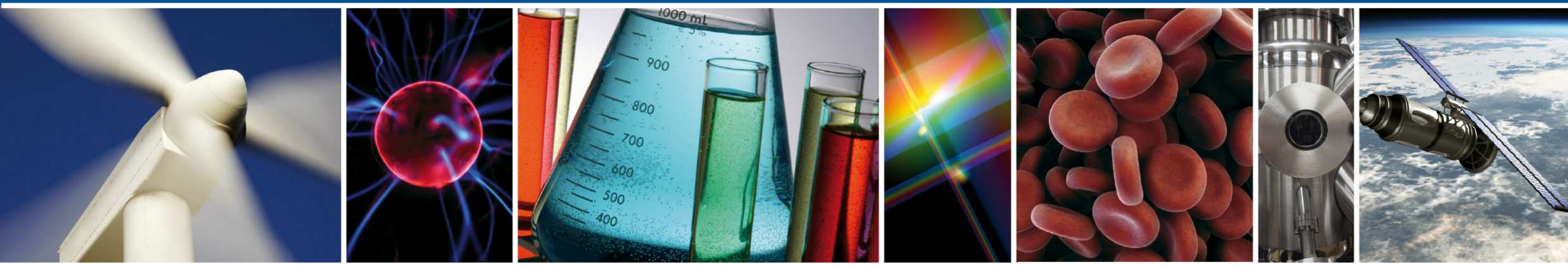
National Measurement System



SENSITIVITY STUDY OF LNG ENERGY TRANSFER UNCERTAINTY FROM COMPOSITION AND TEMPERATURE CHANGES

EMRP
European Metrology Research Programme
Programme of EURAMET

EURAMET
European Association of National Metrology Institutes

www.tuvnel.com

nel
technology for life

- The work described in this report was carried out by NEL Ltd under contract to the Department for Business Innovation & Skills as part of the National Measurement System's Engineering & Flow Programme
- The research leading to these results has received funding from the European Union on the basis of Decision No 912/2009/EC. The EMRP is jointly funded by the EMRP participating countries within Euramet and the European Union.

Contracts Manager
NEL
Scottish Enterprise Technology Park
East Kilbride G75 0QF

E-mail: jduff@tuvnel.com
Tel: +44 (0) 1355-593742

TUV SUD NEL Ltd
EAST KILBRIDE
GLASGOW G75 0QF
UK
Tel: +44 (0)1355 220222
Fax: +44 (0)1355 272999
www.tuvnel.com/flow

SENSITIVITY STUDY OF LNG ENERGY TRANSFER UNCERTAINTY FROM COMPOSITION AND TEMPERATURE CHANGES

A Report for

EMRP ENG-03 LNG Project

Prepared by:	Approved by:
E M Graham	A MacGillvray / A Kenbar

For
Michael Valente
Managing Director
Date: 20 September 2012

CONTENTS

1 INTRODUCTION

This work is part of the European Metrology Research Programme (EMRP) for Liquefied Natural Gas (LNG). The overall objective of this project is to reduce the uncertainty in the evaluation of LNG energy transfers by improving existing measurement methods, validating new measurement methods and development of new traceable calibration systems.

This report forms part of Work Package 4, namely Task 4.6 "Assessing impact of temperature, composition and density gradients in tanks on the total measurement uncertainty".

Task 4.6.2 involves developing an uncertainty model for the LNG energy transfer to assess the impact of temperature and composition gradients in LNG tanks on the density and gross calorific value calculations and overall energy transfer.

A discussion on temperature and composition gradients in LNG cargo tanks is given in section 5.

2 OBJECTIVES

The objectives of the task are:

- Develop a calculation model to determine the uncertainty of LNG energy transfer.
- Utilise the calculation model to assess the effect of composition and temperature changes on the uncertainty of the LNG density, gross calorific value and total energy transfer.

3 APPROACH

The approach taken was to develop an uncertainty calculation model in Microsoft Excel to determine the overall LNG energy transfer uncertainty. This incorporates the uncertainty in the LNG volume, density and gross calorific value.

The LNG transferred energy can be calculated using the following formula:

$$E = (V_{LNG} \cdot D_{LNG} \cdot GCV_{LNG}) - E_{Gas\ Displaced} \pm E_{Gas\ to\ ER}$$

where:

- E_{LNG} is the overall LNG energy transfer
- V_{LNG} is the volume of LNG
- D_{LNG} is the density of the LNG
- GCV_{LNG} is the gross calorific value of the LNG
- $E_{gas\ displaced}$ is the energy of the displace gas, e.g. gas sent back onshore by the LNG carrier when loading

- $E_{gas\ to\ ER}$ is the energy of the gas consumed in the LNG carrier's engine room (+ve for LNG loading transfer and –ve for LNG unloading transfer)

Under some agreements the energy of the displaced gas ($E_{gas\ displaced}$) and energy of gas consumed in the LNG carrier's engine room ($E_{gas\ to\ ER}$) can either be determined or a fixed value can be agreed between parties. For the purpose of this study the value of the displaced gas and energy of gas consumed in the engine room were not considered, partly due to lack of data and in many cases the uncertainty contribution from the displaced gas and gas consumed in the engine is considered negligible [1,2,3].

Having developed the uncertainty model for LNG energy transferred, an assessment of the effect of composition and temperature changes on the uncertainty of the LNG density, calorific value and total energy transfer can be made.

4 UNCERTAINTY BUDGETS

The uncertainty of the LNG energy transferred is determined from the uncertainties of the:

- Calorific value (GCV_{LNG})
- Density (D_{LNG})
- Volume (V_{LNG})

The uncertainty of the calorific value is determined from the uncertainties of the:

- Composition
- Calorific value of the components

The uncertainty of the density is determined from the uncertainties of the:

- Composition
- Density calculation model
- Experimental data used to derive the density model
- Temperature

The uncertainty of the composition is determined from the uncertainties of the:

- Sampling and vaporisation process
- Gas chromatography equipment
- Calibration gas

The uncertainty of the volume has been assessed in a different task in the EMRP project [4].

Both the uncertainty of the calorific value and density depend on the uncertainty of the composition of the LNG, hence these uncertainties are correlated and are not independent. This means that the method for combining the uncertainty values must account for this mutual dependence. Uncorrelated uncertainties are combined by a technique known as root sum square or quadrature. Each contribution to output uncertainty is squared, the squares are summed and the overall uncertainty is taken to be the square root of this summation. This accounts for the unlikelihood that all the source uncertainties will be at their extreme values simultaneously and that to sum the input contributions directly would result in an overly pessimistic view of the overall uncertainty. However, correlated uncertainties are added by simple arithmetic addition to account for the mutual dependence on the same measurements.

Appendix 1 provides a general overview on measurement uncertainty.

It should be noted that some uncertainty values quoted from available references and in this report are based on numerical examples from a specific data set. Therefore, the uncertainty values can change if the input parameters vary, such as the uncertainty of the equipment and composition. For example, the uncertainty values provided by Enagas are numerical examples based on specific data.

4.1 Uncertainty from Measurement Instruments

Although the uncertainty of the instrumentation used for measuring the temperature and pressure has not been evaluated in this study, some of the parameters that should be considered for determining an uncertainty budget are listed below.

- Calibration Standard
- Acceptance Tolerance
- Repeatability
- Drift
- Resolution
- Stability
- Atmospheric Pressure (maybe required for pressure transmitter uncertainty)
- Temperature Correction (for pressure transmitter uncertainty)

4.2 LNG Composition Uncertainty

The determination of the composition of the LNG is important as it is required to calculate the calorific value and density of the LNG. These values are then used to determine the quantity of LNG in terms of energy for custody transfers and hence their measurement uncertainty can have significant financial implications.

The composition of the LNG is determined from sampling the LNG liquid flow, vaporising and analysing the gas using gas chromographic (GC) techniques. More details on LNG sampling are found in [5].

Conservative values were used to determine the uncertainty of the LNG composition. The uncertainty contributions considered were the:

- Chromatograph calibration
- Uncertainty in composition of calibration gas
- Sampling and vaporisation process

Selection of suitable calibration gases with a composition similar to the LNG being transferred and measured was acknowledged as potentially an important factor in minimising uncertainty [1]. In some cases, the variety of calibration gases maybe limited and operators will have to use what is available. For this reason conservative values of ±0.5% were used in this study for the calibration gas components uncertainty although reference [6] provided a value for the calibration gas uncertainty as ±0.1 % of the methane composition.

The uncertainty contribution from the sampling and vaporisation process has been incorporated into the composition uncertainty rather than as a separate contribution in the uncertainty of the gross calorific value (GCV) and density. It was noted that the GIIGNL Handbook only considered the uncertainty of sampling and vaporisation in the calorific value and not in the density calculation [2].

The uncertainty generally accepted for the sampling and vaporisation process by industry for custody transfer is ±0.30 % (k=2). Although well designed sampling and vaporisation systems, in which there is no partial vaporisation before the vaporiser unit, have been assessed to have uncertainty values as low as ±0.2 % (k=2) in the composition of the methane [7]. The value of ±0.30 % (k=2) has been considered to represent the uncertainty in composition from the sampling and vaporisation process.

The uncertainty in the measurement of methane composition in the LNG was estimated by reference [6] to be ±0.11% (k=2). However, in the present study a conservative value for the CG calibration uncertainty of ±0.2% was used.

Table 1 below is taken from the uncertainty calculation spreadsheet which shows the expanded relative uncertainty (k=2) for each component for an example of LNG composition.

Table 1
Uncertainty of the LNG composition

Chromatograph Calibration Uncertainty (%)	0.2

Gas Component	**% mol**	Calibration Gas Uncertainty (%)	Sampling uncertainty (%)	Combined Uncertainty (% mol/mol)
Methane	90.072	0.5	0.3	0.616
Nitrogen	0.192	0.5	0.3	0.616
Ethane	6.381	0.5	0.3	0.616
Propane	2.301	0.5	0.3	0.616
i-Butane	0.415	0.5	0.3	0.616
n-Butane	0.623	0.5	0.3	0.616
i-Pentane	0.014	0.5	0.3	0.616
n-Pentane	0.002	0.5	0.3	0.616
Hexane	0.000	0.5	0.3	0.616

The combined uncertainty in each component is the “root sum square” combination of the chromatograph calibration uncertainty, calibration gas uncertainty and the sampling uncertainty. For comparison the uncertainty values for each component from reference [8] are presented in Appendix 2.

4.2.1 Determining Repeatability

It was noted when reviewing existing uncertainty budgets that methods for calculating the repeatability can widely vary, which can result in a wide variation of values. For determining the repeatability in the GC analysis, usually the data from the GC is assessed to ensure large fluctuations in the data are removed from the overall determination of the LNG composition. Large fluctuations can be most noticeable at the beginning and end of the LNG transfer period when the flow is unstable. It is considered good practise to ensure the large fluctuations or spikes in the GC data are removed to reduce any bias in the results [7]. After the removal of composition data that is out-with set criteria there tends to exist a large data set (greater than 30 points) to determine the average composition due to continuous or intermittent sampling during the transfer of the LNG. The uncertainty in any one data point can usually be considered to be much larger than the average value of a large data set.

Provided there is large data set of greater than 30 points, which provides a statistically meaningful data set, then the uncertainty in the mean composition value can be calculated as:

$$\text{Standard uncertainty in mean value}\,(U_{\text{mean}}) = \frac{\text{Standard deviation}}{\sqrt{(\text{sample population, n})}}$$

Increasing the number of data points from the analysis that are inside the set criteria will reduce the uncertainty in the mean value for each of the LNG components.

4.3 LNG Composition Uncertainty Contribution to the Density and GCV Uncertainty

The effect of composition uncertainty on the overall uncertainty of the LNG, gross calorific value (GCV) and density may be evaluated in several ways. The method used here is to vary the proportions of individual components to determine the effects each has on the overall mixture GCV and density of a specific LNG example. Table 2 shows the values of the incremental changes in the composition and effect on the density and GCV values. The coloured cells show the composition of the component that has been changed. In the last column the composition of all components were varied at the same time. The value of the incremental changes was determined from the uncertainty of the components as given below:

$$\text{Incremental change} = \%_{component} + \left(\frac{\%_{component} . U_{component}}{100}\right)$$

Where:

- $\%_{component}$ is the percentage of the component in LNG
- $U_{component}$ is the combined uncertainty on the LNG component

For example, for methane the values would be $90.072+\left(\frac{90.072\times0.616}{100}\right)=90.627$

Table 2
Effect of varying the composition on the GCV and density values

(The coloured cells highlight that the composition has been modified)

	Composition	Methane	Nitrogen	Ethane	Propane	i-Butane	n-Butane	i-Pentane	n-Pentane	Hexane	All
Methane	90.072	90.627	90.072	90.072	90.072	90.072	90.072	90.072	90.072	90.072	90.627
Nitrogen	0.192	0.192	0.193	0.192	0.192	0.192	0.192	0.192	0.192	0.192	0.193
Ethane	6.381	6.381	6.381	6.420	6.381	6.381	6.381	6.381	6.381	6.381	6.420
Propane	2.301	2.301	2.301	2.301	2.315	2.301	2.301	2.301	2.301	2.301	2.315
i-Butane	0.415	0.415	0.415	0.415	0.415	0.418	0.415	0.415	0.415	0.415	0.418
n-Butane	0.623	0.623	0.623	0.623	0.623	0.623	0.627	0.623	0.623	0.623	0.627
i-Pentane	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
n-Pentane	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Hexane	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Δ Density	0.000	0.018	-0.003	-0.102	-0.067	-0.017	-0.026	-0.001	0.000	0.000	-0.197
Density	458.479	458.461	458.482	458.580	458.545	458.496	458.505	458.480	458.479	458.479	458.676
CV	54.522	54.527	54.521	54.520	54.521	54.522	54.522	54.522	54.522	54.522	54.522
Δ CV	0.000	-0.005	0.001	0.002	0.001	0.000	0.001	0.000	0.000	0.000	0.000

	Max Difference	Absolute Uncertainty	Relative Uncertainty
Density	0.214883	0.214883	0.046869
Calorific Value	0.006845	0.006845	0.012554

The maximum difference in the calculated density and calorific value was used as the uncertainty contribution as this provided the most conservative values. It can be seen that the uncertainty in LNG composition has a more significant contribution to the uncertainty of the density than for the gross calorific value.

Table 3 describes the alternative approaches that can be applied to the model.

Table 3
Methods for determining the composition uncertainty contribution to the GCV and Density

Approach	Method	Method description
Optimistic	Half difference	Estimates the uncertainty as half of the maximum differences from the calculations of the various compositions
Pessimistic	Max. difference	Estimates the uncertainty as the maximum differences from the calculations of the various compositions
Moderate	Max. difference from median	Estimates the uncertainty as the maximum differences between the median and the most extreme results from the calculations of the various compositions

For comparison the values of composition uncertainty from available references are:

- composition uncertainty of ±0.063 % of the molecular weight (k=1) with uncertainty contribution towards density as ±0.043 % (k=1) [3]
- composition uncertainty contribution to the density as ±0.09 % (k=1) [2]
- sampling uncertainty of ±0.3% (k=1) and chromographic analysis uncertainty of ±0.03% (k=1) contributions towards the calorific value uncertainty [2]

- uncertainty in methane composition is ±0.46 % mol/mol (uncertainty values are provided for all the components) [8]
- gas analysis uncertainty of ±0.09% (k=3) towards the density uncertainty [9]
- calibration gas composition uncertainty of ±0.03% (k=3) and sampling and vaporisation uncertainty of ±0.3% (k=3) contributions towards the calorific value uncertainty [9]

4.4 Density Uncertainty

The density was calculated using the revised Klosek-McKinley model as described in the GIIGNL [2]. The revised Klosek-McKinley model was reviewed in Work Package 4 of the EMRP project and described in detail in the report "Assessment of calculation methods for LNG density" [10].

Table 4 shows the uncertainty budget for the LNG density. The divisor (k) is used to convert the expanded uncertainty (U) with k values given in the table (approximately 95% coverage) to the standard uncertainty (u) with k=1. The product of the standard uncertainty (u) and the sensitivity (c) determines the contribution to the uncertainty of the LNG density. In this example all the sensitivity values are equal to one as the components uncertainties are in the same units as density, e.g. the temperature uncertainty of 0.2^{o}C has been converted into a density uncertainty. The total uncertainty is determined from a quadratic summation (root mean square) of all the contributions and expressed as the expanded uncertainty (U) with k=2.

Table 4
Uncertainty budget for the LNG density

				Uncert.			Divisor	Stand. Unc	Sens. ($\partial f/\partial x_i$)	Product	Square
Rank	**Source**	**Units**	**Value**	**U**	**U^*%**	**Distribution**	**k**	**u**	**c**	**u.c**	**$(u.c)^2$**
5	Composition	kg/m^3	458.479	0.215	0.047	Rectangular	1.732	0.124	1	0.124	1.54E-02
2	Revised Klosek-McKinley Method	kg/m^3	458.479	0.458	0.100	Rectangular	1.732	0.265	1	0.265	7.01E-02
4	Exp data to derive K-M Model	kg/m^3	458.479	0.275	0.060	Normal	2.000	0.138	1	0.138	1.89E-02
3	Temperature (±0.2 ^{o}C)	kg/m^3	458.479	0.320	0.070	Rectangular	1.732	0.185	1	0.185	3.41E-02
1	Temp - Field experience (additional ±0.3 ^{o}C)	kg/m^3	458.479	0.480	0.105	Rectangular	1.732	0.277	1	0.277	7.68E-02
	Combined uncertainty	kg/m^3	458.479	0.928	0.202	Normal	2	0.464	1	0.464	2.15E-01

Correlation of uncertainty contributions:

- The molecular masses of the components are assumed to be 100 % correlated as they are calculated from the same values of atomic masses – this was considered negligible.
- Mole fractions of the components are assumed to be 100 % correlated due to the use of the same analysis equipment and normalisation procedure. This is accounted for by taking the maximum difference in the density value as the composition uncertainty contribution as described in section 4.3.
- Correction factors K_1 and K_2 and the molar volume of the components are assumed to be 100 % correlated as they depend on the LNG molecular mass – this was not considered and assumed to be accounted for by taking the maximum difference in the density value as described in section 4.3.

- Correction factors K_1 and K_2 and the molar volume of the components are also correlated as they depend on the LNG temperature – this effect was evaluated separately in section 4.4.2.

Values of the uncertainty of the density from available references are:

- ±0.21 % (k=1) [2]
- ±0.16 % (k=2) [3]
- ±0.23 % (assumed k=3) [9]
- ±0.35 % (k=2) [8]

The uncertainty contributions to the density uncertainty from the available references are listed below.

GIIGNL [2] – the confidence level of the uncertainties is taken at k=1 as the values have been used to determine the overall energy transfer standard uncertainty with k=1

- Density calculation method estimated by NBS report [9] to be ±0.10 % (k=1)
- Composition error estimated by NBS report [9] to be ±0.09 % (k=1)
- Temperature ±0.5^{o}C giving uncertainty in density of ±0.16% (k=1)
- Overall uncertainty in the density by quadratic summation is ±0.21% (k=1)

MetroPartner a.s. Report [3]

- Temperature ±0.25^{o}C (k=2)
- Pressure ±0.022 bar (k=2)
- Calculation method ±0.1% (k=2)
- Composition ±0.063% (k=1)
- Overall uncertainty in the density by quadratic summation is ±0.16% (k=2)

NBS Report [9]

- Systematic errors of ± 0.14 % (k unknown) (quadratic summation)
  - Experimental data to derive density model, ±0.1% (k unknown)
  - Using density model, ±0.1% (k unknown)

- Random errors of ± 0.091% (k=3) (quadratic summation)
  - Composition ±0.09% (assumed k=3) (arithmetic addition of random and systematic errors) as follows:
    - Random error of ±0.06% (k=3) from the scatter of data
    - Calibration gas composition of ±0.03% (assume k=3) (systematic error)
  - Maximum error in temperature of ±0.1K (k unknown), determined to be ±0.016 % in density.
  - Pressure, ±0.001% from ±1.8 kPa (regarded as negligible)

- Total uncertainty in density is ±0.23% (assumed k=3) from arithmetic addition of random and systematic errors.

In reference [9] some of the uncertainties have no k value quoted. The uncertainties quoted with a k value used k=3. It has been assumed that a consistent approach was used in the original reference and then assumed in this report that the overall uncertainties are with k=3.

4.4.1 Density Model Uncertainty Contribution

The uncertainty commonly quoted for the revised Klosek-McKinley model to determine the LNG density is ±0.1% [2,3]. A comprehensive study to assess the LNG density models [9] quoted that the revised Klosek-McKinley model can predict the density to within ±0.1% based on evaluation using experimental data with an uncertainty of ±0.1%. The uncertainty evaluation by reference [9] incorporated the uncertainty from using the model and the experimental data. This conservative approach was adopted in this uncertainty budget. Reference [9] determined the experimental uncertainty taking a conservative approach using three standard deviations. Using the industry-standard approach of two standard deviations reduces the uncertainty to ±0.06%, this value was used in this model.

It was noted that the GIIGNL only considers uncertainty of the model used (±0.1%) and does not include the uncertainty contribution from the sampling and vaporisation in the composition uncertainty.

4.4.2 Temperature Uncertainty Contribution

The revised Klosek-McKinley model requires only the LNG composition and temperature for calculation of LNG density.

The correlation through temperature was addressed by varying the temperature by a set amount (e.g. 0.5°C) and the effect this has on the volume correction value, V_c, (V_c incorporates correction factors K_1 and K_2) and the molar volumes of the components was calculated. The density difference was calculated when varying the temperature on one component and this difference was used as the uncertainty contribution for each molar volume.

Values are presented in Table 5 with both the correlated and uncorrelated uncertainty components.

The uncorrelated uncertainty was determined from quadratic summation (root mean square) of all the contributions (u.c) to give ±0.069% (k=2).

The correlated uncertainty contributions (u.c) are added by simple arithmetic addition to account for the mutual dependence on the same measurements. In this model the correlated uncertainties are assumed to be 100% (i.e. fully) correlated. The correlated uncertainty was determined as ±0.07% (k=2).

Comparison of the correlated and uncorrelated uncertainties shows insignificant difference using this uncertainty method.

Table 5

Uncertainty budget for the temperature contribution to LNG density

(values determined for Δt = 0.2 ^{o}C)

Rank	Source	Units	Value	Uncertainty U	U^{*}%	Distribution	Divisor k	Stand. Unc u	Sensitivity ($\partial f/\partial x_i$) c	Product u.c	Uncorrel. Square $(u.c)^2$
1	Methane molar volume	kg/m^3	458.479	0.272	0.059	Rectangular	1.732	0.157	1	0.157	2.47E-02
5	Nitrogen molar volume	kg/m^3	458.479	0.003	0.001	Rectangular	1.732	0.002	1	0.002	2.36E-06
3	Ethane molar volume	kg/m^3	458.479	0.012	0.003	Rectangular	1.732	0.007	1	0.007	5.14E-05
4	Propane molar volume	kg/m^3	458.479	0.005	0.001	Rectangular	1.732	0.003	1	0.003	7.78E-06
7	i-Butane molar volume	kg/m^3	458.479	0.001	0.000	Rectangular	1.732	0.001	1	0.001	3.12E-07
6	n-Butane molar volume	kg/m^3	458.479	0.001	0.000	Rectangular	1.732	0.001	1	0.001	6.38E-07
8	i-Pentane molar volume	kg/m^3	458.479	0.000	0.000	Rectangular	1.732	0.000	1	0.000	4.16E-10
9	n-Pentane molar volume	kg/m^3	458.479	0.000	0.000	Rectangular	1.732	0.000	1	0.000	7.97E-12
10	Hexane molar volume	kg/m^3	458.479	0.000	0.000	Rectangular	1.732	0.000	1	0.000	0.00E+00
2	Volume correlation (Vc)	kg/m^3	458.479	0.018	0.004	Rectangular	1.732	0.010	-1	-0.010	1.06E-04
	Combined correl. uncertainty	kg/m^3	458.479	0.320	0.070	Normal	2.000	0.160	1	0.160	
	Combined uncorrel. uncertainty	kg/m^3	458.479	0.316	0.069	Normal	2	0.158	1	0.158	2.49E-02

Table 6 shows the uncertainty budget for the density using temperature sensitivity values determined by calculating the effect of a small change in temperature (e.g. 0.5^{o}C) on the density (i.e., $\partial\rho/\partial T = \Delta\rho/(T_{+}-T_{-})$). Comparing the different methods for determining the density uncertainty in Table 4 with that in Table 6 gives an insignificant difference in the density uncertainty of ±0.014%.

Table 6
Uncertainty budget for the LNG density using temperature sensitivity method

									Sensitivity		
				Uncertainty			Divisor	Stand. Unc	($\partial f/\partial x_i$)	Product	Square
Rank	**Source**	**Units**	**Value**	**U**	**U*%**	**Distribution**	**k**	**u**	**c**	**u.c**	**(u.c)²**
5	Composition	kg/m³	458.479	0.215	0.047	Rectangular	1.732	0.124	1	0.124	1.54E-02
1	Klosek-McKinley Method	kg/m³	458.479	0.458	0.100	Rectangular	1.732	0.265	1	0.265	7.01E-02
4	Exp data to derive K-M Model	kg/m³	458.479	0.275	0.060	Normal	2.000	0.138	1	0.138	1.89E-02
3	Temperature	°C	-160.000	0.2	-0.125	Rectangular	1.732	0.115	-1.3709	-0.158	2.51E-02
2	Temp - field experience	°C	-160.000	0.3	-0.188	Rectangular	1.732	0.173	-1.3709	-0.237	5.64E-02
	Combined uncertainty	kg/m³	458.479	0.862	0.188	Normal	2	0.431	1	0.431	1.86E-01

Sensitivity of Density to Temperature

INPUT

Temperature	T_+	T_-
-160.000	-159.500	-160.500

SENSITIVITY

Density:	c_t
	-1.3709

DENSITY

Effect of Temperature Variation

ρ_+	ρ_-	$\Delta\rho$
457.794	459.165	-1.371

The uncertainty of the temperature value has been quoted by various sources as:

- ± 0.25°C (k=2) [3]
- ± 0.5°C (k=1) [2]
- ± 0.1 K (assumed k=3) [9]
- ± 0.17°C (k=2) [8]
- ± 0.2°C (k=2) [11]
- ± 0.3°C (k=2) [12]

The tolerance for temperature measurement equipment quoted by ISO 10976 is ± 0.2 °C [11]. However, a more conservative value of ± 0.5°C (i.e. sum of ±0.2 and ±0.3 in Table 4) was used in these models.

It can be concluded that the uncertainty in the density is ±0.20 % (k=2) for this specific example. This uncertainty model is applicable for other cargoes with different compositions and temperatures. The sensitivity study in section 5 determines the density uncertainty for 461 different LNG cargoes.

4.5 Gross Calorific Value Uncertainty

The calorific value of the LNG was determined on a mass basis using ISO 6976 [13] at standard conditions 15°C and 1.01325 bara. Superior calorific values were used in compliance with GIIGNL.

Values of the uncertainty of the calorific value from available references are:

- ±0.30% (k=1) [2]

- ±0.15% (k=2) [3] (NB this uncertainty value is for the product of the density times the calorific value to account for correlation)
- ±0.35% (assumed k=3) [9]
- ±0.08% (k=2) [14]

The uncertainty contributions to the calorific value uncertainty from the available references are listed below.

GIIGNL [2] – The uncertainties making up the gross calorific value uncertainty are not expanded, i.e. k=1 and these are used to determine the standard uncertainty in LNG energy transfer:-

- Sampling and vaporisation estimated by NBS report [9] of ±0.30 % (k=1)
- Calibration gas composition error estimated by NBS report [9] of ±0.03 % (k=1)
- Gross calorific value of components estimated by NBS report to be ±0.04 % (k=1)
- Overall uncertainty in the calorific value by quadratic summation is ±0.30% (k=1)

MetroPartner a.s. Report [3] – uncertainty was determined as the product of the density and calorific value to account for correlation through composition:-

- Temperature ±0.25^{o}C (k=2)
- Pressure ±0.022 bar (k=2)
- Gross calorific value method ±0.052% (k=2)
- Density method ±0.1% (k=2)
- Composition ±0.063% (k=1)
- Overall uncertainty in the (calorific value times the density) by quadratic summation is ±0.15% (k=2)

NBS Report [9]

- Systematic errors of ± 0.05 % (k unknown) (quadratic summation)
  - Calibration gas composition of ±0.03% (k unknown)
  - Gross calorific value of components ±0.04 % (k unknown)
- Random errors of ± 0.3 % (k=3) (includes gas analysis precision of ±0.06% (k=3) and sampling and vaporisation uncertainty)
- Total uncertainty in calorific value is ± 0.35 % (assumed k=3) from arithmetic addition of random and systematic errors

Within the uncertainty model developed here the uncertainty contributions towards the LNG calorific value were the composition and calorific values from the LNG components. The contribution from the calorific values of the components was taken from ISO 6976 [13] as the uncertainty of the calorific value of methane since this is the major component. The uncertainty of the calorific value of methane is quoted as ±0.06 MJ/kg (at 95% confidence level).

Correlation of the molecular masses of the LNG components (as these are determined from the same values of atomic masses) was not included as this was considered to be insignificant compared to other uncertainty contributions.

Correlation of the mole fractions for the LNG components from using the same analysis equipment and normalisation procedure was considered to be accounted for in the composition uncertainty. This was done by taking a conservative approach to determine the uncertainty by taking the maximum difference in the calculated GCV values (see section 4.3).

Table 7 shows the uncertainty budget for the calorific value of LNG. In this table the uncertainty in LNG composition is taken from the analysis presented in section 4.3 and Table 2. As indicated above, the uncertainty in LNG composition has much less significant contribution to the uncertainty of calorific value than for density.

Table 7
Uncertainty budget for the Gross Calorific Value

				Uncert.			Divisor	Stand. Unc	Sens. (∂f/∂x$_i$)	Product	Square
Rank	Source	Units	Value	U	U*%	Distribution	k	u	c	u.c	(u.c)^2
2	Composition	MJ/kg	54.522	0.007	0.013	Rectangular	1.732	0.004	1	0.004	1.56E-05
1	CV value of components	MJ/kg	54.522	0.060	0.110	Normal	2.000	0.030	1	0.030	9.00E-04
	Combined uncertainty	MJ/kg	54.522	0.061	0.111	Normal	2	0.030	1	0.030	9.16E-04

It can be concluded that the uncertainty of the calorific value is 0.11% (k=2) for this specific example. The sensitivity study in section 5 shows the uncertainty results from 461 LNG cargoes.

4.6 Volume Uncertainty

The volume uncertainty contribution has been reviewed and determined as part of a separate study within the EMRP project in reference [4]. Values from the EMRP study and from other references are presented in Table 8.

Table 8
Reference values for the volume uncertainty

Tank Type	Gauge Level Type	U* (%)	k	Ref
Membrane	Radar	0.53	2	4
Moss	Float	0.38	2	4
Spherical	Radar	0.31	2	3
Membrane	Float	0.30	2	3
Membrane	Capacitance	0.30	2	3
Membrane	Radar	0.14	2	15
Membrane	-	0.09	1	2
Prismatic	-	0.12*	-	9
Membrane	-	0.16*	-	9
Spherical	-	0.04*	-	9
-	Capacitance, float, radar	0.30	2	12

*Value for a single tank - assumed to be same for all tanks

The most conservative value of ±0.53% (from the EMRP study) has been used to determine the overall uncertainty of the energy transfer of LNG. The GIIGNL value of 0.094 is calculated from five tanks as ±(0.21/√5) assuming that all contributions are independent and are not correlated. This is highly unlikely in practice and therefore the uncertainty value determined for the volume of one tank of ±0.21 % (k=1) is more representative.

4.7 Uncertainty in Total Energy Transfer

The uncertainty contributions from the density, calorific value and volume have a degree of correlation towards the total LNG energy uncertainty. The density and calorific value both have a dependence on the composition of the LNG. The volume of the LNG has a dependence on the LNG temperature, (which is also required for density calculation), composition and density. The uncertainty contribution from the density, calorific value and volume were first treated as completely uncorrelated and then 100% correlated to obtain extreme uncertainty values. These uncertainties are presented in Table 9.

Table 9
Uncertainty budget for Total LNG Energy for Uncorrelated and 100% Correlated Uncertainties

INPUTS

	Value	Unit	Uncertainty	U(%)
Volume	122034	m^3	53.48	0.53
Density	458.479	kg/m^3	0.928	0.202
Calorific Value	54.522	MJ/kg	0.061	0.111

OUTPUT UNCERTAINTIES

	Value	Unit	Uncertainty	U(%)
Energy	3050515810	MJ	13380840	0.439

Estimate of Uncertainty in Total Energy

			Uncertainty			Divisor	Stand. Unc	Sensitivity $(\partial f/\partial x_i)$	Product	Uncorrel. Square
Source	**Units**	**Value**	**U**	**U^*%**	**Distribution**	**k**	**u**	**c**	**u.c**	**$(u.c)^2$**
Calorific Value	MJ/kg	54.522	0.061	0.111	Normal	2.000	0.030	55950004	1693000	2.87E+12
Density	Kg/m^3	458	0.928	0.202	Normal	2.000	0.464	6653559	3087440	9.53E+12
Volume	m^3	122034	646.780	0.53	Normal	2.000	76.408	24997.262	1909980	3.65E+12
Combined correlated uncertainty	MJ	3050515810	13380840	0.439	Normal	2	6690420	1	6690420	
Combined uncorrel. uncertainty	MJ	3050515810	8011631	0.263	Normal	2	4005816	1	4005816	1.60E+13

The uncertainty contributions from the displaced gas and gas consumed by the engine can be considered in the determination of the overall energy transferred uncertainty. However, in this study these were considered negligible and not necessary for the sensitivity study due to their small values.

From Table 9 it can be seen that the uncorrelated uncertainty in LNG energy transferred is ±0.26% while the 100% correlated uncertainty is ±0.44 %. The level of correlation is difficult to determine and usually is assumed to be 50%. In this report a conservative approach was taken by using 80% correlation. Figure 1 shows the effect of selecting different degrees of correlation on the value of the uncertainty.

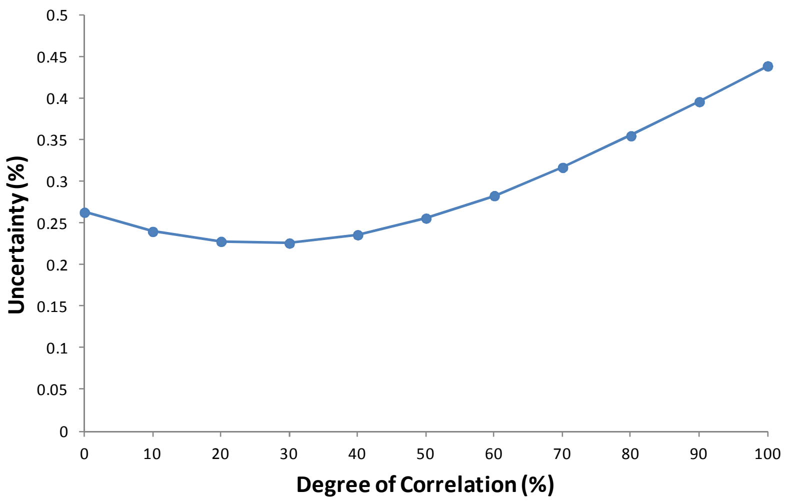


Figure 1 – Effect of the degree of correlation on the uncertainty

Table 10 shows the LNG energy uncertainty budget using 80% correlation. The correlated uncertainty contribution from the calorific value, density and volume was determined by taking 80% of the product of the standard uncertainty and sensitivity coefficient (u.c). The sum of the (u.c) values was taken as the overall correlated uncertainty contribution to the LNG energy. The uncorrelated uncertainty contribution from the calorific value, density and volume was determined by taking 20% of the product of the standard uncertainty and sensitivity coefficient (u.c). The root mean square of the (u.c) values was then taken as the overall uncorrelated uncertainty contribution to the LNG energy.

The uncorrelated (±0.05%) and correlated (±0.35%) expanded uncertainty contributions were combined by the root mean square method to provide an overall LNG energy uncertainty of ±0.36% (k=2).

Table 10
Uncertainty budget for Total LNG Energy for 80% Correlated Uncertainties

Estimate of Uncertainty in Total Energy

			Uncertainty			Divisor	Stand. Unc	Sensitivity ($\partial f/\partial x_i$)	Product	% correlation	Correl.	Uncorrel.
Source	**Units**	**Value**	**U**	**U^*%**	**Distribution**	**k**	**u**	**c**	**u.c**		**(u.c)**	**$(u.c)^2$**
Calorific Value	MJ/kg	54.522	0.061	0.111	Normal	2.000	0.030	55950004	1693000	80	1.35E+06	1.1465E+11
Density	Kg/m^3	458	0.928	0.202	Normal	2.000	0.464	6653559	3087440	80	2.47E+06	3.8129E+11
Volume	m^3	122034	646.780	0.53	Normal	2.000	76.408	24997.262	1909980	80	1.53E+06	1.4592E+11
Uncertainty of correlated components	MJ	3050515810	10704672	0.351	Normal	2	5352336.198	1	-	-	5.35E+06	-
Uncertainty of uncorrel. Components	MJ	3050515810	1602326	0.053	Normal	2	801163.1057	1	-	-	801163.11	6.42E+11
Combined correlated and uncorrel. uncertainty	MJ	3050515810	10823930	0.355								

Values of the uncertainty of the total energy transfer from available references are:

- ±0.76% (k=2) [2]
- ±0.34 % (k=2) [3]
- ±0.46 % (k value not provided) – uncertainty value for unloading from a single tank [9]

Reference [2] and [9] assumed no correlation between the density, volume and calorific value and combined the overall uncertainties in quadrature. Reference [3] took account of correlation.

From comparison with these references the overall uncertainty of the total energy transfer in this study of ±0.36 % (k=2) agrees with reference [3] despite using a different approach. However, it must be noted that this is applicable to the specific example given in this study and dependant on the uncertainty contributions taken from available literature for volume, density and calorific value. A complete independent calculation of uncertainty in energy transfer requires significant effort which is beyond the scope of this study.

5 SENSITIVITY STUDY

Originally part of Task 4.6.1 was to collect data sets for temperature from probes in the liquid in each of the LNG tanks for a range of cargoes before unloading or after loading and also collect composition data. The purpose of this data was to assess temperature and composition gradients within the tanks. Data on temperature distribution (in the liquid and vapour regions) along the LNG tanks are available since these are used to calculate the average temperature in these regions depending on liquid level in the tank. However, data on LNG composition variations over the height of the tank are not required during custody transfer operations and therefore this data is not available. The LNG composition is measured on shore from sampling and chromatographic analysis as described fully in [5].

Discussions with experts at the 2nd International Workshop on Metrology for LNG on 31st October 2011 highlighted that temperature stratification of the LNG or temperature and composition gradients within the cargo tanks are negligible during loading and unloading processes as there is sufficient movement of the fluids from the pumping process to ensure adequate mixing of the LNG. Even during LNG transport between loading and unloading locations there is sufficient movement of the fluids from the motion of the ship. Temperature and composition gradients can occur when tanks have had sufficient time to ‘settle’ and there is insufficient movement of the fluids to ensure mixing.

Discussions with experts on in-situ measurements of the LNG density by radar tank gauge support these claims [16]. The technique can determine the density of LNG at different levels in an LNG tank and show if there are density gradients which would result from temperature and/or composition gradients.

The original objective of Task 4.6.2 was to use data from Task 4.6.1 to determine the impact of temperature and composition gradients in tanks on the density, calorific value and overall uncertainty of the LNG energy transfer calculations. Due to the reasons mentioned above, the objective of this task changed to a parametric sensitivity study of the impact of composition and temperature variation in LNG cargoes on the overall uncertainty of the LNG energy transfer. The purpose of the sensitivity study is to highlight the significance of these variations should they exist.

5.1 Data for Sensitivity Study

Enagas provided an extensive set of composition and temperature data for 461 cargoes, a selection of which are presented in Appendix 3. The data from the 461 cargoes were used as the input data for uncertainty model for the energy transfer of LNG. The temperature of the cargoes ranged from -162.32°C to -156.64°C. Figure 2 shows the variation in the LNG temperature across the cargoes.

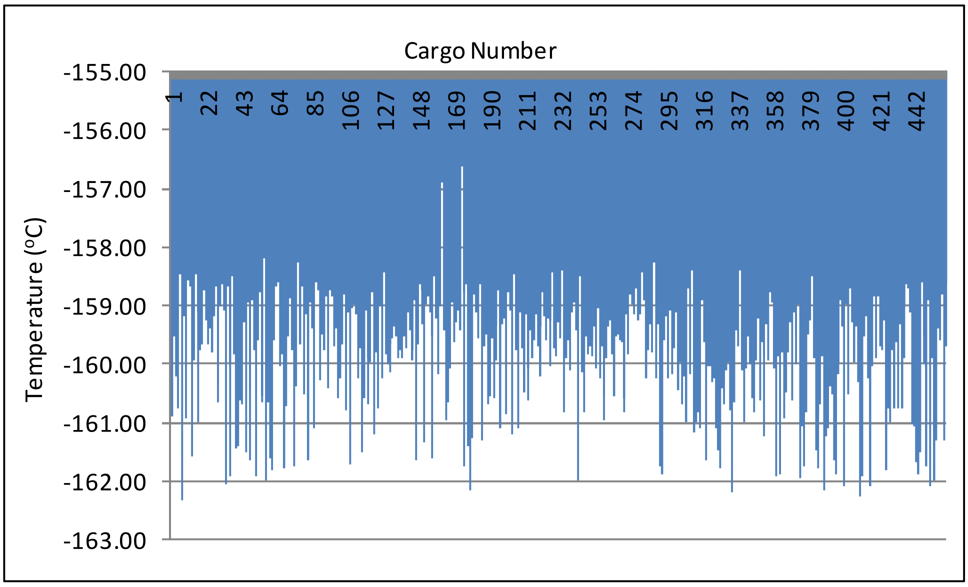


Figure 2 - Temperature variation across the 461 LNG cargoes

Table 10 shows the composition range of the components of the LNG from these cargoes and Figure 3 show the variation in methane content across the cargoes.

Table 10
Composition range of the components from 461 LNG cargoes

Composition	Lowest value (%)	Highest value (%)
Methane	79.154	97.717
Ethane	2.128	15.41
Propane	0.048	4.678
i-Butane	0	0.633
n-Butane	0	0.724
i-Pentane	0	0.062
n-Pentane	0	0.045
Hexane	0	0.023
Nitrogen	0.002	1.082
Carbon dioxide	0	0

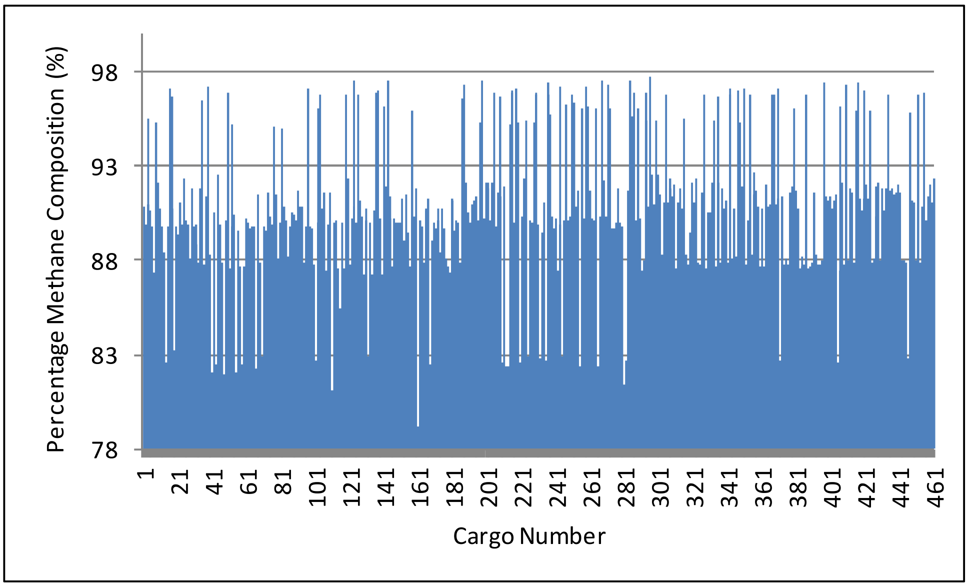


Figure 3 - Percentage methane variation across the 461 LNG cargoes

5.2 Results from Sensitivity Study

The 80% correlation model was used for the sensitivity study. The results from the sensitivity study showed that the uncertainty of the energy transfer of LNG varied from ±0.35% to ±0.36% with an average value of ±0.36%. Table 11 details the number of cargoes with each uncertainty value.

Table 11
Number of LNG cargoes with uncertainty value of the total energy transferred (k=2)

Number of cargoes	Uncertainty value
26	±0.35 %
435	±0.36 %

Table 12 shows the range of percentage uncertainty values from the composition, density and calorific value.

Table 12
Range of uncertainty values from the composition, density and calorific value from the 461 LNG cargoes (k=2)

Uncertainty	Lowest value	Highest value
Composition uncertainty contribution to density (%)	± 0.046	± 0.074
Uncertainty in density (%)	± 0.188	± 0.204
Composition uncertainty contribution to calorific value (%)	± 0.003	± 0.026
Uncertainty in calorific value (%)	± 0.108	± 0.116

Figures 4 to 6 show the variation in the expanded relative uncertainty (k=2) in the LNG calorific value, density and energy across the 461 LNG cargoes, respectively.

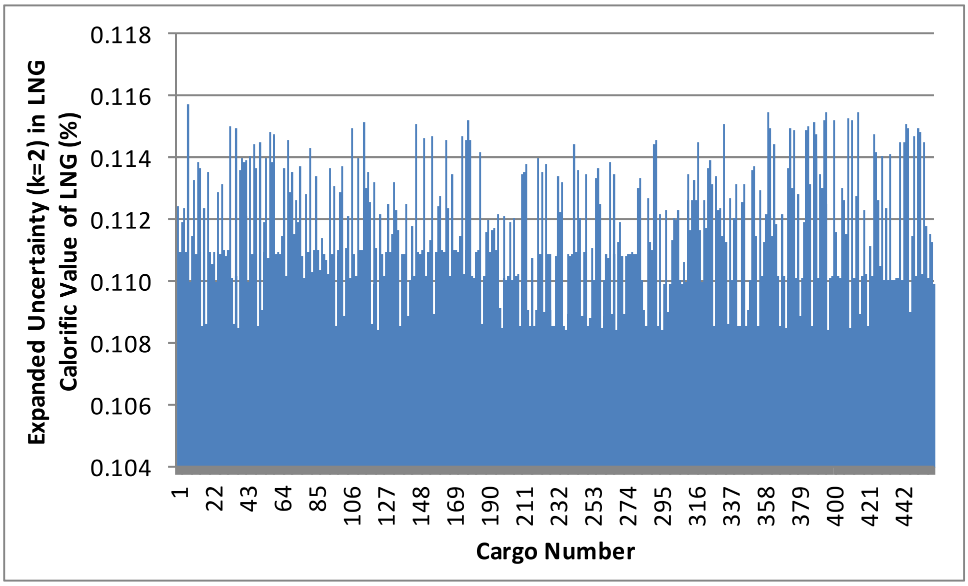


Figure 4 - Expanded uncertainty in GCV across the 461 LNG cargoes

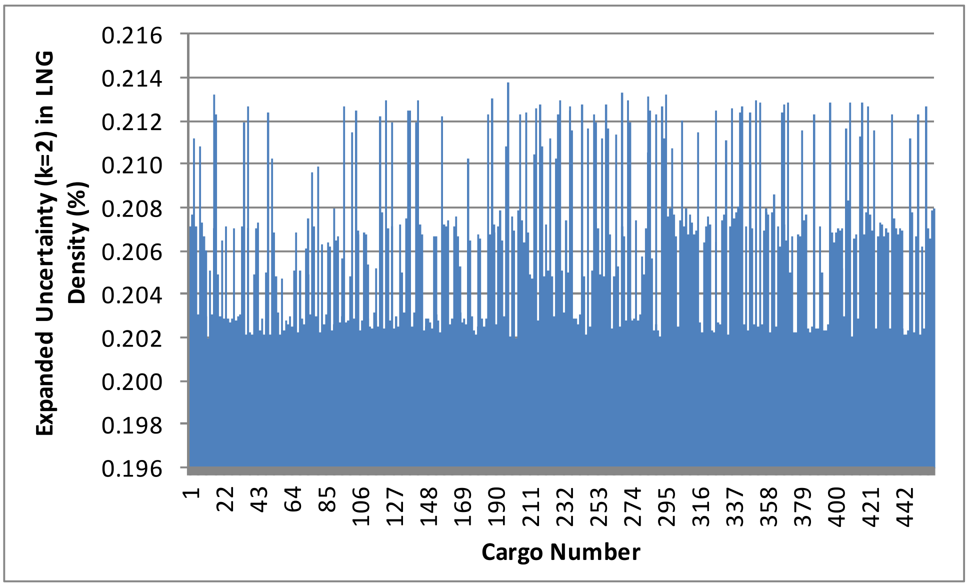


Figure 5 - Expanded uncertainty in density across the 461 LNG cargoes

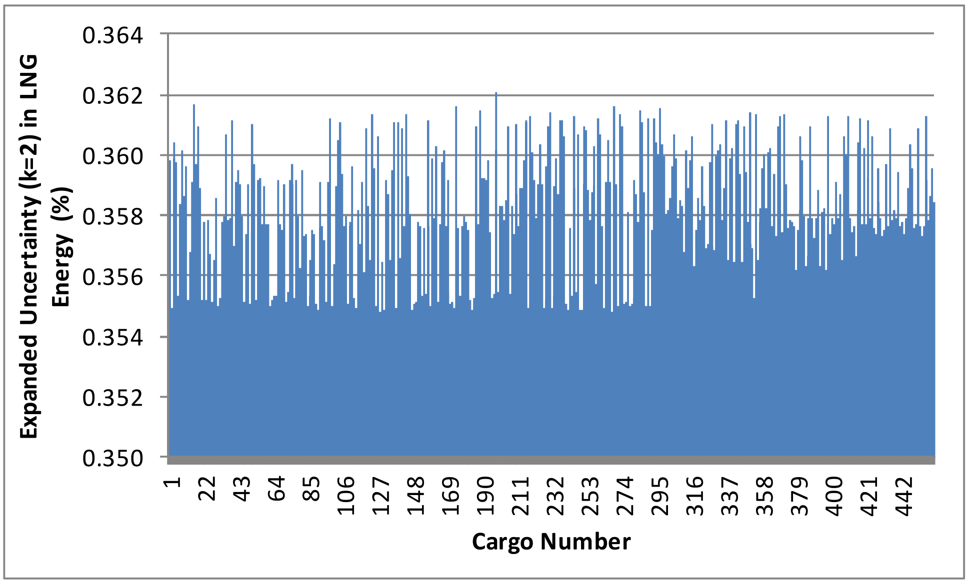


Figure 6 - Expanded uncertainty in energy across the 461 LNG cargoes

6 CONCLUSIONS

A model was developed to determine the uncertainty in the LNG energy transfer and this was used to assess the sensitivity to changes in composition and temperature.

The results show that the uncertainty in density, calorific value and overall LNG energy transfer are not significantly sensitive to the changes in temperature or composition within the typical range seen in LNG cargoes. The values should cover all types of tanks as conservative values were used.

The model was used to assess the uncertainty from 461 LNG cargoes and determined the range in uncertainty values as:

- Uncertainty in density between ±0.19% and ±0.20%
- Uncertainty in gross calorific value between ±0.11% and ±0.12%
- Uncertainty in total energy transfer between ±0.35% and ±0.36%.

It is important to note that uncertainty results presented in this study were dependant on the uncertainty contributions taken from available literature and current industry experience for the volume uncertainty and the elements contributing to the density and calorific value uncertainties. A complete independent calculation of uncertainty in energy transfer requires significant effort which is beyond the scope of this study.

The uncertainty of the different parameters involved in the global uncertainty of the energy transferred ideally should be calculated for each cargo and equipment used. Therefore, it can be difficult to determine an uncertainty range or upper limit because the values depend on the quality of the measurement at each terminal.

7 RECOMMENDATIONS

1) The use of Monte Carlo simulation may have been beneficial to apply a range of values for the input parameters (e.g. composition, temperature etc) to determine the range and distribution of variations in the overall energy transfer value. One of the advantages of this method is the availability of the output distribution and to determine if the output is skewed.

2) Due to the variation in methods and values for the uncertainty in overall energy transfer, guidelines for producing a realistic uncertainty budget would be beneficial. It was noted that many companies produce in-house uncertainty budgets rather than rely on the GIIGNL values [2].

3) It would be beneficial to produce an additional uncertainty budget table for the energy transferred using the source input parameters from the density, calorific value and volume. This includes LNG temperature, composition, ship list and trim measurements, start and end liquid level measurements, start and end tank volume measurements, density model etc. The sensitivity coefficients determined would account for correlation. This model would eliminate the need to assume the percentage correlation dependence for the density, calorific value and volume.

NOMENCLATURE

u Standard uncertainty

U Expanded uncertainty

U* Relative expanded uncertainty is the expanded uncertainty expressed as a percentage of the parameter

k Coverage factor

c Sensitivity coefficient

UNCERTAINTY GLOSSARY

Uncertainty	Parameter, associated with the results of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand.
Standard uncertainty	Uncertainty of the result of a measurement expressed as a standard deviation.
Combined standard uncertainty	Standard uncertainty of the result of a measurement when that result is obtained from the values of a number of other quantities, equal to the positive square root of a sum of terms, the terms being the variances or covariances of these other quantities weighted according to how the measurement result varies with changes in these quantities.
Expanded uncertainty	Quantity defining an interval about the result of a measurement that may be expected to encompass a large fraction of the distribution of values that could reasonably be attributed to the measurand: the fraction may be viewed as the coverage probability or the level of confidence of the interval.
Coverage factor	Numerical factor used as a multiplier of the combined standard uncertainty in order to obtain an expanded uncertainty: k is typically in the range 2 to 3.
Sensitivity coefficient	Determines the relationship between the input uncertainty and the resulting output uncertainty and is defined as the change of the output quantity that will result from a unit change in the input value.
Type A evaluation	Method of evaluation of uncertainty by the statistical analysis of a series of observations.
Type B evaluation	Method of evaluation of uncertainty by means other than the statistical analysis of a series of observations.
Tolerance	The permitted variation in a measurement. Machines used in manufacturing often set tolerance intervals, or ranges in which product measurements will be tolerated or accepted before they are considered flawed.

REFERENCES

[1] Discussion with A. Benito at Cartagena LNG terminal, Spain, December 2011.

[2] GIIGNL, LNG Custody Transfer Handbook, 3rd edition, 2010.

[3] R. Sakariassen, MetroPartner a.s. report "Uncertainty evaluation of LNG energy determination at Melkoya by use of ship tanks", Doc no. REP-02/1004, Nov 2004.

[4] EMRP report (JV, VSL, FORCE) "Evaluation of uncertainty in transferred LNG volume", Nov 2011.

[5] A Kenbar, "Assessment of LNG Sampling Systems" NEL Report No: 2012/349, NEL, East Kilbride, UK. Report for EMRP ENG-03 LNG.

[6] EffecTech, "Grain LNG Importation Terminal Import Gas Quality Measurement System", Report reference 11/180/06, 3rd August 2011.

[7] A. Benito, "Accurate determination of LNG quality unloaded in receiving terminals: An innovative approach".

[8] A. Benito, Enagas report INF-I-529-11, "Uncertainty in the LNG density determination: Klosek-McKinley Revised Method", June 2011.

[9] "LNG Measurement – A User's Manual for Custody Transfer", National Bureau of Standards, US, NBSIR 85-3028, 1st edition, 1985.

[10] A. Kenbar, "Assessment of calculation methods for LNG density", East Kilbride, UK. Report for EMRP ENG-03 LNG, in preparation.

[11] BS ISO 10976:2012 "Refrigerated light hydrocarbon fluids – Measurement of cargoes on board LNG carriers".

[12] Elengy report, Contract providing access to the LNG terminal, Version 1st Jan 2010, "Appendix 4 - Measuring, Metering, Quality".

[13] ISO 6976:2005. "Natural gas– Calculation of calorific values, density, relative density and Wobbe index from composition".

[14] A. Benito, Enagas report INF-I-539/11, "Uncertainty in the determination of the Gross Calorific Value of LNG", August 2011.

[15] A. Benito, Enagas report INF-I-518/11, "Determination of the uncertainty of the volume unloaded from an LNG carrier", March 2011.

[16] O. Jensen, "Measurement of LNG density by radar tank gauge", 2nd International Workshop on Metrology for LNG, 31st October 2011.

APPENDIX 1

Overview of Measurement Uncertainty

When we make a measurement of a quantity the result that we obtain is not the actual true value of the quantity, but only an estimate of the value. This is because no instrument is perfect; there will always be a margin of doubt about the result of any measurement.

Expressing uncertainty

The uncertainty of a measurement is the size of this margin of doubt; in effect it is an evaluation of the quality of the measurement. To fully express the result of a measurement three numbers are required:

- The measured value. This is simply the figure indicated on the measuring instrument.
- The uncertainty of the measurement. This is the margin or interval around the indicated value inside which you would expect the true value to lie with a given confidence level.
- The level of confidence attached to the uncertainty. This is a measure of the likelihood that the true value of a measurement lies in the defined uncertainty interval. In industry the confidence level is usually set at 95% which corresponds to a coverage factor k value of 1.96. This value is normally approximated to 2.

Error vs Uncertainty

Very often people confuse error and uncertainty by using the terms interchangeably. Uncertainty is the margin of doubt associated with a measurement. Error is the difference between the measured value and a reference value. In financial terms the expression of uncertainty allows us to estimate the degree of exposure caused by a measurement. For example, if an oil field produces 10,000 barrels per day and the cost of oil is $100 per barrel then if your flow meter over-reads by ±1% you will lose $20,000 every day. Uncertainty is also a vital part of the calibration process where the uncertainty should be reported on the certificate.

Evaluating Uncertainty

The process of evaluating the uncertainty of an individual measurement involves a series of simple and logical steps.

1. Define the relationship between all of the inputs to the measurement and the final result. For example, a measurement may have uncertainty in the calibration and the resolution of the measuring instrument.

2. Draw up a list of all of the factors that you consider to contribute to the uncertainty of the measurement. This may mean that you consult with the operator who is taking the measurement and best knows the system.
3. For each of the sources of uncertainty that you have identified, make an estimate of the magnitude of the uncertainty.
4. For the relationship described in **STEP 1**, estimate the effect that each input has on the measurement result.
5. Combine all of the input uncertainties using the appropriate methodology to obtain the overall uncertainty in the final result.
6. Express the overall uncertainty as an interval about the measured value within which the true value is expected to lie with a given level of confidence.

Common Sources of Uncertainty

1. The measuring instrument
   The instrument may be affected by influences such as drift between calibrations, the effect of aging, bias in the instrument, electronic noise and mechanical vibration.
2. The effect of the environment
   Changes in operating conditions such as temperature, pressure and humidity can increase uncertainty.
3. Operator Skill
   Especially when the instrument is complex, some of the measurements depend on the skill and experience of the operator. Following set procedures properly is also a very important discipline.
4. The process of taking the measurement
   This can sometimes present problems. It may be that an operator has to read an analogue display with a needle that is fluctuating between two limits on the dial of an instrument.
5. Variation in the measured quantity
   Often when we are measuring a quantity its value may fluctuate over time. This introduces an element of uncertainty that should be accounted for

APPENDIX 2

Expanded Uncertainty of the LNG Components from Reference [8]

Values include reference gas mixture uncertainty, GC calibration uncertainty, analysis uncertainty and sampling uncertainty.

Component	Expanded Uncertainty (% mol/mol) (k=2)
Methane	± 0.46
Ethane	± 0.41
Propane	± 0.18
i-Butane	± 0.059
n-Butane	± 0.13
i-Pentane	± 0.0045
n-Pentane	± 0.0024
Hexane	± 0.0015
Nitrogen	± 0.028

APPENDIX 3

Example of Composition and Temperature Data Provided By Enagas for the Sensitivity Study

(This shows the data from only 15 cargoes taken from a data set of 461 cargoes)

	Composition											
Cargo #	C1 (%)	C2 (%)	C3 (%)	IC4 (%)	NC4 (%)	IC5 (%)	NC5 (%)	C6 (%)	N2 (%)	CO2 (%)	T(ºC)	Sum
1	90.866	7.766	0.645	0.007	0.006	0.000	0.000	0.000	0.710	0.000	-160.89	100.000
2	89.949	6.540	2.305	0.418	0.625	0.008	0.001	0.000	0.154	0.000	-159.51	100.000
3	90.940	7.892	0.538	0.000	0.000	0.000	0.000	0.000	0.630	0.000	-160.20	100.000
4	95.509	3.267	0.832	0.208	0.157	0.006	0.002	0.000	0.019	0.000	-159.32	100.000
5	90.682	7.987	0.624	0.002	0.000	0.000	0.000	0.000	0.705	0.000	-160.76	100.000
6	89.826	6.647	2.310	0.418	0.628	0.009	0.001	0.000	0.161	0.000	-158.47	100.000
7	87.415	8.785	2.026	0.288	0.400	0.004	0.000	0.000	1.082	0.000	-162.32	100.000
8	95.299	3.433	0.867	0.215	0.161	0.006	0.001	0.000	0.018	0.000	-159.17	100.000
9	92.185	5.157	2.095	0.308	0.218	0.000	0.000	0.000	0.037	0.000	-159.00	100.000
10	90.777	8.012	0.675	0.005	0.002	0.000	0.000	0.000	0.528	0.000	-160.93	100.000
11	81.241	13.595	3.990	0.334	0.382	0.018	0.006	0.000	0.434	0.000	-158.58	100.000
12	89.792	6.636	2.372	0.425	0.638	0.010	0.002	0.000	0.125	0.000	-158.66	100.000
13	88.373	8.610	1.814	0.161	0.175	0.018	0.016	0.000	0.833	0.000	-161.59	100.000
14	82.569	12.557	3.594	0.309	0.354	0.019	0.005	0.000	0.593	0.000	-159.92	100.000
15	89.826	6.603	2.351	0.423	0.635	0.010	0.002	0.000	0.150	0.000	-158.48	100.000