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## ACCURACY OF CV DETERMINATION SYSTEMS FOR CALCULATION OF FWACV

### EXECUTIVE SUMMARY


### BACKGROUND

Estimates of the accuracy of domestic consumer billing have been made. The approach used is based on the principles given in a guidance note produced by Marcogaz and is based on estimates of sources of bias and uncertainty in bias of each of the steps used to derive consumers' energy bills. Such sources include measurement equipment (notably the domestic meter, NTS offtake meters and NTS offtake CV determination devices), assumptions behind the fixed factors used for volume conversion required by the Gas (Calculation of Thermal Energy) Regulations, and the variation in CV experienced by consumers in a particular charging area.

Having made estimates of consumer billing accuracy, the impact of reducing the accuracy of CV determination for entry of small volumes of gas is estimated. The principal driver for reducing the accuracy of CV determination is to reduce obstacles to uptake of use of renewable gas supplies such as biomethane, but the approach is applicable to entry of small volumes of any gas.

### CONCLUSIONS

1) For a typical LDZ, where uncertainty in bias in NTS offtake metering and CV determination are around ±4% and ±0.1 MJ/m3 respectively, the bias in domestic energy metering is estimated to be: -0.445% ±7.42%. The dominant sources of bias and uncertainty in bias are associated with fixed factors for conversion of actual domestic metered volume to reference temperature and pressure.
2) For a typical LDZ, the bias in LDZ energy is estimated to be: 0% ±2.04%. The bias in LDZ energy resulting from the LDZ model is zero because the model assumes that daily volumes and daily CVs are unbiased.
3) Current custom and practice is for Ofgem to require that (absolute) error in CV measured by CV determination equipment should not exceed 0.10 MJ/m$^3$. This requirement results in insignificant impact on domestic energy metering.
4) Some relaxation in Maximum Permissible Error (MPE) in CV determination may be appropriate, particularly in low volume applications, such as biomethane injection, for which the anticipated daily volumes are so low as to make CV determination accuracy insignificant in respect of impact on the domestic consumer. The appropriate MPE should be decided by consideration of other regulatory issues (such as monitoring of compliance with the GS(M)R if shared duty is being practiced), or normal commercial factors for sale of energy. However, daily flows of up to 2.5 million m$^3$ could be measured with devices having an MPE of ±0.5 MJ/m$^3$ with no material impact on accuracy of FWACV and hence domestic consumer energy billing.
5) In addition to MPE, a formal performance specification for CV determination devices should include a maximum bias shown by CV determination devices with gases that the instrument (or family of instruments) is likely to see.
6) Accuracy of CV determination of comingled mixtures will dictate how far from the FWACV the CV of the comingled gas can be allowed to deviate. Lower accuracy CVDDs will require CV of the comingled gas to be stay relatively close to the anticipated FWACV.

### RECOMMENDATION

1) CV determination devices with a maximum permissible error of ±0.5 MJ/m$^3$ are recommended for all credible flows of biomethane into gas distribution systems.
2) A framework for type approval of CVDDs is recommended. The salient features of such a framework are set out in the report.

ACCURACY OF CV DETERMINATION SYSTEMS FOR CALCULATION OF FWACV

# 1 INTRODUCTION

Energy billing of domestic gas consumers is generally based on the actual volume of gas consumed, converted to a volume at reference conditions of temperature and pressure. The resultant *quantity*[1] of gas is then converted to energy by multiplying it by a calorific value (CV) that is *representative* of that received by consumers in a given charging area. Generally, the billing CV applied by gas suppliers is the average of daily values provided by National Grid for each charging area, or Local Distribution Zone (LDZ), over the billing period of the consumer. The conversion of actual volume to volume at reference conditions and the determination of daily charging area CVs is governed by the Gas (Calculation of Thermal Energy) Regulations 1996 and Amendment 1997 ("the Regulations").

Volume conversion is performed by gas suppliers by use of national fixed factors that account for variation of temperature and pressure of gas in the meter. These factors are provided in the Regulations and are based on principles and methods originally used by British Gas Corporation prior to privatisation of the UK gas industry.

Daily charging area CVs are calculated by National Grid from determinations of daily CVs for all relevant inputs to, and relevant outputs from, a particular charging area. The methodology for calculating daily charging area calorific values is prescribed in the Regulations and permits either use of "lowest source" or "flow weighted average" approaches. Flow Weighted Average Calorific Value (FWACV) has been the method of choice by the then Transco, and now the four Gas Distribution Networks, since the amendment to the Regulations in 1997 which permitted its use.

FWACV is calculated from daily CVs calculated for individual relevant inputs to and outputs from a particular charging zone, which in turn are based on individual determinations of CV made by gas transporters using instruments that have been approved by Ofgem. The location and manner of determination of CV is formally prescribed through Letters of Direction from Ofgem to the gas transporter. The Letter of Direction requires the use of instruments that are approved by Ofgem and this approval is formally given by Ofgem to the gas transporter through the use of a Letter of Approval. Currently two types of instrument are approved by Ofgem: a combustion calorimeter manufactured by Cutler Hammer and two variants of the gas chromatograph manufactured by Daniels Industries Ltd ("the Danalyzer").

There is no agreed specification for the required performance of instruments for determination of CV, although custom and practice has led to the use of certain criteria for initial and regular performance evaluation of gas chromatographic systems:

a) Error in CV determined by the instrument when presented with gases of different composition.

b) Repeatability of the composition determined by the instrument when presented with gas of constant composition.

The criterion for acceptable error in CV is generally for error to be no more than +/- 0.1 $MJ/m^3$. Initially this criterion was applied for four hypothetical test compositions agreed with Ofgem. However, with increased PC power, use of Monte Carlo (MC) methods has been used to determine error for a large (typically tens of thousands) set of hypothetical compositions. This approach has been taken to align performance evaluation with some of the more advanced concepts of error and uncertainty in use by the natural gas metrology community.

The criterion of Maximum Permissible Error of +/- 0.1 $MJ/m^3$ is historical and dictated by Danalyzer performance, rather than any notion of fairness to or impact on the domestic consumer for whom the CV determination is principally directed. As a result, in 2006 Ofgem requested a view on the impact of this criterion on the domestic consumer and in 2006 a National Grid report[2] set out a methodology for assessing and quantifying its impact.

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[1] Because the volume of a gas increases and decreases with increasing temperature and pressure, respectively, it does not define a quantity of gas. Instead actual volume is converted to a volume the gas would have occupied, had it been at reference conditions of temperature and pressure. The volume at reference conditions can be considered a quantity. The UK gas industry has adopted ISO reference conditions of 15$^{o}$C and 1.01325 bar.

[2] "Accuracy of CV determination systems for calculation of FWACV". National Grid Measurement and Process Report MPR071. October 2006.

In late 2011 Ofgem instigated the setting up of the EMIB Review Panel[3] under the stewardship of the Joint Office of Gas Transporters with the aim of addressing the outstanding technical and commercial barriers thought to the injection of biomethane into gas distribution and transportation systems. One such barrier is the cost associated with CV determination devices (CVDDs) and the question of the appropriate level of accuracy of CVDDs and in particular those associated with biomethane injection (the flows of which inevitably represent a relatively small fraction of the energy flowing into a charging area, even under the most optimistic of future scenarios).

The work carried out in 2006 and reported in MPR071 has therefore been updated to address the issue of small flows of biomethane (or any other gas, for that matter) into charging areas and the impact of different levels of CV determination accuracy on the consumer. This report describes both the original work published in 2006 and the recent work carried out for EMIB.

## 2 METHODOLOGY FOR ASSESSMENT OF IMPACT OF CVDD INSTRUMENT ACCURACY

The approach taken in assessing impact is based on the principles and recommendations developed by the Marcogaz Energy Measurement Working Group[4]. Essentially the process sets out the bias and uncertainty in bias for all component parts that together make up the determined quantity of energy. Bias is defined here as the mean of a distribution of errors of a series of determinations.

Biases for each component part are combined by arithmetic addition, whereas uncertainties in biases are combined by addition in quadrature.

### 2.1 DOMESTIC METER

Assuming that the domestic gas meter is unbiased and complies with the in-service requirements of BS EN1359 (MPE 3%) the bias is estimated to be zero with a standard uncertainty of 1.5%.

### 2.2 CONVERSION TO VOLUME AT REFERENCE CONDITIONS

A number of components make up the conversion factor employed to convert actual volume to volume at reference conditions and are described in turn below.

Atmospheric pressure. The correction factor in the Regulations assumes an atmospheric pressure of 1013.25 mbar. For the UK[5] mean monthly atmospheric pressure from 1987 to 1996 was estimated to be described by a distribution with mean 1015.20 mbar and a standard deviation of 24.43mbar, so the bias in atmospheric pressure is taken to be -1.95 mbar, with a standard uncertainty in bias of 24.43 mbar.

Meter pressure. The correction factor in the Regulations assumes meter pressure regulator is set at a pressure of 21 mbarg. IGE/GM/8 Part 1 specifies an accuracy of 7.5% (preferred) or 10% (limit) of set gauge pressure for domestic meter regulators with an inlet gauge pressure of between 21 and 100 mbar. Bias in meter gauge pressure is therefore taken to be zero, with a standard uncertainty in meter pressure of 1.05 mbar ((0.1 x 21)/2). The divisor 2 is based on an assumption that the accuracy requirements of IGE/GM/8 Part 1 can be interpreted as an expanded uncertainty corresponding to a probability of around 95%.

Altitude. The correction factor in the Regulations is based on a nominal altitude of 66m above sea level. In practice the correction factor is based on the use of an altitude adjustment to pressure of -8.114 mbar. This value is derived from Table in Part 1 the Regulations (height above sea level band >65.0, ≤67.5m), which in turn is derived from an altitude of 67.5m in the formula that was in use by British Gas prior to the Regulations coming into force:

pressure deduction = altitude in metres * 0.120208

The value 0.120208 is the altitude correction factor. For the UK[5] mean altitude was estimated to be described by a distribution with mean 67.16 m and a standard deviation of 54.55 m, so the bias in altitude is taken to be +0.34 m, with a standard uncertainty in bias of 54.55 m.

[3] Ofgem Review Group on Energy Market Issues for Biomethane Projects

[4] “Guidance note on energy determination: implementation of certain principles presented in relevant standards.” Marcogaz, October 2006.

[5] L.M.Wallis. “Examination of environmental factors affecting gas metering accuracy”. BG Technology Report R2278 April 1998.

The value of altitude correction factor (0.120208 mbar/m) was in use by British Gas prior to the Regulations coming into force. This value is assumed to have zero bias and a standard uncertainty of 0.0012 mbar/m (1%).

Temperature. The correction factor in the Regulations assumes a gas temperature of 12.2 $^{o}$C. For the UK[5] mean monthly atmospheric pressure from 1987 to 1996 was estimated to be described by a distribution with mean 11.9 $^{o}$C, with a half-range of 11.2 $^{o}$C, so the bias in gas temperature is taken to be +0.3 $^{o}$C, with a standard uncertainty in bias of 5.6 $^{o}$C (11.2/2).

Zb/Z. The correction factor in the Regulations assumes that non-ideality of the gas can be ignored, i.e. Zb/Z = 1. Actual values of Zb/Z were estimated for the UK based on gas composition data for 2005 at a pressure of 1028.125 mbar and 11.9 $^{o}$C (i.e. the conditions of temperature, pressure and altitude above) and from this the bias in Zb/Z was estimated to be 0.000184 with a standard uncertainty of 0.0000049.

Truncation and rounding. The correction factor in the Regulations is a combination of three factors a temperature factor, a pressure factor and a Z factor:

$$\frac{T_b}{T}\frac{P}{P_b}\frac{Z_b}{Z}$$

In the Regulations the correction factor employs a value for the temperature factor $\frac{T_b}{T}$ of 1.0098 instead of the exact value. In addition the final value is truncated to 1.02264.

Combining all of the above components results in a bias in conversion factor of -0.318% and a standard uncertainty in bias of 3.1497%.

## 2.3 CONVERSION TO ENERGY

Components making up the conversion to energy are as follows:

Actual CV. Although the billing CV is used for consumer billing, a consumer may actually receive gas of CV up to 1 MJ/m3 lower than that used for billing. The billing CV may therefore be in error (from an individual consumer's perspective) by up to 1 MJ/m3. The bias in actual CV is therefore assumed to be zero with a standard uncertainty in bias of 0.5 MJ/m3 (1.0/2).

Billing CV. Bias in billing CV and its uncertainty are governed by bias and uncertainty associated with the FWACV, which is in turn dependent upon: variation in daily CV of all sources of gas into the charging area, the bias and uncertainty in bias in the CVDD at the relevant inputs and outputs to the charging area, and the bias and uncertainty in bias in the daily volume measurement equipment at the relevant inputs and outputs to the charging area. Bias and uncertainty in bias in billing CV were estimated for North West LDZ daily volumes and daily CV seen in 2005, using combinations of accuracy for CVDD and daily volume measurement system. The details and methodology are given in Section 3. The billing CV is actually the average of the daily CVs calculated for the billing period, so over a typical 91 day billing period the uncertainty in the average billing would be the uncertainty of the daily CVs divided by √91 if the daily CVs were uncorrelated. However for this exercise daily CVs assumed to be perfectly correlated. This probably over-estimates the uncertainty, but errors in CV are likely to be related strongly to composition, so if similar gases are seen throughout the charging period then errors are likely to be similar

Truncation of the billing CV. The Regulations require the average billing CV to be truncated to 1 dp. Assuming that over time the digit of the 2$^{nd}$ decimal place of the billing CV is equally distributed between 0 and 9 suggests that truncation results in a bias of -0.05 MJ/m$^3$ with standard uncertainty in bias of 0.5/√3 = 0.29.

Combining all of the above components results in a bias in energy conversion of -0.126% and a standard uncertainty in bias of 1.2679%.

# 3 BIAS AND UNCERTAINTY IN BIAS IN BILLING CV

Billing CV is the average of each daily FWACV calculated over the billing period. Bias in billing CV will depend upon how the bias in FWACV varies over that time and for simplicity this is assumed to be constant across the billing period. In the absence of a capped FWACV, bias in FWACV is assumed to be zero and hence bias in billing CV is assumed to be zero. This assumption is valid so long as the measurements of daily calorific values and daily volumes are unbiased, i.e., they show a distribution of errors that are centred about zero. Uncertainty in error in billing calorific value will depend on the uncertainty in daily FWACV values and how strongly the daily FWACV values are correlated. If the FWACV values were uncorrelated, the uncertainty in bias in billing calorific value would be smaller than that of the FWACV by a factor of $\sqrt{91}$ for a 13-week (91day) billing period. Clearly some components of FWACV are strongly correlated (e.g., Danalyzer performance over a billing period is relatively constant) and so the most conservative estimate of uncertainty in bias in billing CV is to assume it is that of the daily FWACV.

The bias and uncertainty in bias of the daily FWACV was calculated using a Microsoft Excel spreadsheet model of a sample charging area using data for National Grid's North West LDZ. For each day's data (daily volumes and daily average CVs for each offtake) uncertainty in bias in FWACV was estimated from the analytical solution for the uncertainty .

## 4 BIAS AND UNCERTAINTY IN BIAS IN LDZ ENERGY

The model described in Section 3 also permits the uncertainty in bias in LDZ energy to be estimated.

## 5 RESULTS

### 5.1 BIAS AND UNCERTAINTY IN BIAS IN FWACV

Bias and uncertainty in bias in FWACV was estimated for different combinations of NTS offtake metering and CV measurement accuracy, the extremes in which correspond to the situation like that prevalent today (accuracy of CVDD 0.1 MJ/m$^3$; accuracy of offtake metering around 4%) and an idealised "highest accuracy" situation (accuracy of CVDD 0.1 MJ/m$^3$; accuracy of offtake metering around 1%). The resulting standard uncertainties in bias in FWACV are shown in Table 1 below, expressed as relative %:

Table 1: Standard uncertainty in bias in FWACV, u(bias(FWACV), relative %

| a(E(Vd)) | a(E(CV)) | | | |
|---|---|---|---|---|
| | 0.05 MJ/m$^3$ (0.125%) | 0.10 MJ/m$^3$ (0.25%) | 0.20 MJ/m$^3$ (0.5%) | 0.50 MJ/m$^3$ (1.25%) |
| 1% | 0.0373 | 0.0746 | 0.1491 | 0.3727 |
| 2% | 0.0373 | 0.0746 | 0.1491 | 0.3727 |
| 3% | 0.0373 | 0.0746 | 0.1491 | 0.3727 |
| 4% | 0.0374 | 0.0746 | 0.1491 | 0.3728 |
| 5% | 0.0375 | 0.0746 | 0.1491 | 0.3728 |
| Note: a(Vd) and a(CV) are the assumed uncertainties in daily volume and a(CV) respectively, expressed as half-range values (uniform distribution). | | | | |

The values in Table 1 are those used as estimates of uncertainty in bias in billing CV (see 2.3).

### 5.2 IMPACT ON DOMESTIC CONSUMERS

The output from the domestic energy uncertainty calculations set out in Section 2 is a mean and standard deviation for the distribution of possible errors in energy estimated for the domestic consumer. The distribution arises from combination of the distributions associated with sources of uncertainty or distributions of error.

Table 2 shows the calculation of uncertainty in bias in consumer billing for a typical LDZ, where uncertainty in bias in NTS offtake metering and CV determination are around ±4% and ±0.1 MJ/m$^3$ respectively.

Table 2: Calculation of uncertainty in bias in consumer billing for a typical LDZ

| | Units | Property, P | meanP | bias(P) | bias(P)/P | u(bias(P)) | u(bias(P)/P) | variance | % total variance |
|---|---|---|---|---|---|---|---|---|---|
| **1. Actual billing period volume** | **m3** | **100.00** | **100.00** | **0.00** | **0.000%** | | **1.5000%** | **0.0225%** | **16.33%** |
| atmospheric pressure | mbar | 1013.25 | 1015.20 | | | 24.43 | | | |
| meter pressure | mbarg | 21.00 | 21.00 | | | 1.05 | | | |
| altitude | m | 67.50 | 67.16 | | | 54.55 | | | |
| altitude correction factor | mbar/m | -0.12 | -0.12 | | | -0.0012 | | | |
| Pressure (combined) | mbar | 1026.14 | 1028.13 | -1.9909 | -0.194% | 25.31 | 2.4619% | 0.0606% | 43.99% |
| Temperature | K | 285.35 | 285.05 | 0.3000 | 0.105% | 5.60 | 1.9646% | 0.0386% | 28.01% |
| Zb/Z | - | 1.0000 | 1.000184 | 0.0002 | 0.018% | 0.0000049 | 0.0005% | 0.0000% | 0.000002% |
| Fixed factor | | 1.022654755 | 1.025905981 | | | | | | |
| Truncation of T factor and rounding | | 1.022640000 | 1.025905981 | -0.0033 | -0.318% | | | | |
| **2. Volume conversion** | | **1.022640000** | **1.025905981** | | **-0.318%** | | **3.1497%** | **0.0992%** | **72.00%** |
| CV variation | MJ/m3:E | 39.50 | 39.50 | 0 | 0.000% | 0.5 | 1.2658% | 0.0160% | 11.63% |
| area FWACV | MJ/m3:E | 39.50 | 39.50 | 0 | 0.000% | | 0.0746% | 0.0001% | 0.04% |
| truncation of area CV | MJ/m3:E | 39.50 | 39.55 | -0.05 | -0.126% | 0.032 | 0.0810% | 0.0001% | 0.05% |
| **3. Energy conversion** | **MJ/m3:E** | **39.50** | **39.55** | **-0.050** | **-0.126%** | | **1.2680%** | **0.0161%** | **11.67%** |
| **4. Overall** | **MJ** | **4039.43** | **4057.46** | **-18.03** | **-0.445%** | | **3.7119%** | **0.1378%** | **100.00%** |

Overall:

| | | |
|---|---|---|
| Bias in domestic consumers' bills | -0.445% | |
| Standard uncertainty in bias in domestic consumers' bills | 3.712% | |
| Expanded uncertainty in bias in domestic consumers' bills | 7.4239% | assuming k=2 |

For a typical LDZ the bias in domestic energy metering is therefore estimated to be:

-0.445% ±7.42%

Assuming an average domestic gas bill of £1,000 pa or £2.74 per day this corresponds to a bias in the daily energy bill of:

-£0.01 ±£0.20

Note that the above expanded uncertainty corresponds to 95% of all daily energy estimates and not 95% of consumers.

The above estimate assumes that the standard uncertainty in bias in FWACV is 0.0746% (see Table 1). Table 3 below shows the impact of varying the uncertainty in bias in NTS offtake metering and CV determination. In all cases bias in domestic billing is unaffected and uncertainty in bias is insensitive to accuracy of NTS offtake metering and relatively insensitive to CV determination.

Table 3: Expanded* uncertainty in bias in domestic consumer energy billing

| a(E(Vd)) | a(E(CV)), MJ/m$^3$ | | | |
|---|---|---|---|---|
| | 0.05 | 0.10 | 0.20 | 0.50 |
| 1% | 7.4228 | 7.4239 | 7.4284 | 7.4597 |
| 2% | 7.4228 | 7.4239 | 7.4284 | 7.4597 |
| 3% | 7.4228 | 7.4239 | 7.4284 | 7.4597 |
| 4% | 7.4228 | 7.4239 | 7.4284 | 7.4597 |
| 5% | 7.4228 | 7.4239 | 7.4284 | 7.4597 |
| *Assuming a coverage factor k=2, corresponding to a probability of around 95% | | | | |

## 5.3 BIAS AND UNCERTAINTY IN BIAS IN LDZ ENERGY

Table 4 shows the expanded uncertainty in LDZ energy for the same combinations of uncertainty in NTS offtake metering and CV determination employed in 5.2 above.

For a typical LDZ the bias in LDZ energy is estimated to be:

0% ±2.04%

The bias in LDZ energy resulting from the LDZ model is zero because the model assumes that daily volumes and daily CVs are unbiased.

Expanded uncertainty in bias is relatively insensitive to CV determination and dominated by the accuracy of NTS offtake metering. Typically uncertainty in LDZ energy is around one-half of the offtake metering accuracy and this arises because errors in NTS volumes and CV measurements are assumed to be uncorrelated. For errors in volume this assumption is probably justified, but some correlation between errors in CV measurement might be expected because all Danalyzers employ the same composition of calibration gas and typically show similar response curves for the main component (i.e. methane tends to show a relatively large non-zero intercept in its response). However, the degree of correlation was estimated using performance evaluation data for each Danalyzer associated with the NTS offtakes into the LDZ. Little correlation was actually observed (only one off-diagonal term in the correlation matrix was greater than 0.5). The assumption of uncorrelated errors is therefore justifiable.

Table 4: Expanded* uncertainty in bias in LDZ energy

| a(E(Vd)) | a(E(CV)), $MJ/m^3$ | | | |
|---|---|---|---|---|
| | 0.05 | 0.10 | 0.20 | 0.50 |
| 1% | 0.5146 | 0.5306 | 0.5902 | 0.9028 |
| 2% | 1.0212 | 1.0294 | 1.1612 | 1.2622 |
| 3% | 1.5296 | 1.5350 | 1.5566 | 1.7000 |
| 4% | 2.0384 | 2.0424 | 2.0586 | 2.1690 |
| 5% | 2.5472 | 2.5506 | 2.5636 | 2.6530 |
| *Assuming a coverage factor k=2, corresponding to a probability of around 95% | | | | |

### 5.4 IMPACT OF BIOMETHANE INJECTION

The estimates of bias and uncertainty in bias in Tables 3 and 4 do not consider a future scenario in which injection of relatively small quantities of renewable gases into charging areas. Clearly the impact on consumer billing of injection of low flows of biomethane will be insignificant, since wholesale relaxation of CV determination accuracy to ±0.5 $MJ/m^3$ has little impact (see Table 3). However the impact on accuracy of LDZ energy determination was assessed by reducing the CV determination accuracy at one of two NTS offtakes whilst retaining the current 0.5 $MJ/m^3$ accuracy at all other offtakes. Under these scenarios the expanded uncertainty in bias in LDZ energy increased from ±2.0424% to:

±2.0555%, for an NTS offtake with mean daily volume of 3.09 million $m^3$ (14.8% of LDZ volume)

±2.1266%, for an NTS offtake with mean daily volume of 8.24 million $m^3$ (39.4% of LDZ volume)

In both cases, daily volume at all offtakes is assumed to be ±4%.

The measurement of CV with an accuracy of ±0.5 $MJ/m^3$ is judged to be achievable by relatively low-cost devices and the measurement of biomethane volume with an accuracy of ±4% is readily achievable if compliant with the general principles of IGE/GM/8, for instance.

## 6 DISCUSSION

### 6.1 DOMESTIC METERING

The bias in domestic metering (-0.445%) is relatively small and negative i.e. the energy bill is under-estimated. The sources of bias are: pressure assumptions in the conversion factor (44% of total bias); truncation of billing CV (28%); temperature assumptions in the conversion factor (24%); and gas ideality assumptions in the fixed factor (4%).

The uncertainty in bias (7.42%) and the principal sources are: pressure assumptions in the conversion factor (44% of total variance); temperature assumptions in the conversion factor (28%); domestic meter accuracy (16%); and CV variation (12%). Accuracy of billing CV contributes very little to the overall accuracy of domestic billing (0.04% of variance).

Uncertainty in bias in domestic consumer energy billing leads to cross subsidy from consumers whose bills are over-estimated to those whose bills are under-estimated. The dominant source of this cross-subsidy is associated with conversion of the actual volume of gas metered at consumers' premises in accordance with the fixed factors specified in the Regulations and in particular the assumptions about pressure and temperature of gas metered in domestic premises.

This cross-subsidy could in principle be reduced by direct pressure and temperature correction at the meter or through adoption of LDZ-specific fixed factors. Technically, the greatest reduction would be through volume conversion at the domestic meter, but this would require investment in new metering technology for the domestic meter population. This might be regarded as an unjustifiable expense in its own rights, but it should be noted that installation of smart metering is planned for the UK economically anyway, so the marginal cost of volume conversion is what requires economic test and not the full cost of new meters. Both volume conversion and LDZ-specific fixed factors would require modification of consumer billing systems (not without significant cost) and both would of course require amendment to the Gas (Calculation of Thermal Energy) Regulations.

## 6.2 ACCURACY IN BILLING CV

Energy conversion contributes around 12% of the variance in bias in domestic billing and hence cross-subsidy between consumers. The dominant source of this variance is not the accuracy of CV determination itself, but the variation in the gas actually received by different consumers within a given charging area. Reducing this source of uncertainty could be achieved by CV determination at the domestic meter, transmission to a smart meter of an estimated daily CV from a central location, or reduction in the size of charging area. Similar arguments to that for domestic metering above apply, i.e. marginal cost of CV determination at the meter (using inferential methods, such as speed of sound determination) or facilities for receipt of a transmitted daily CV and the need for billing system and regulatory changes.

The only other means of reducing uncertainty in billing CV is through adoption of higher accuracy standards for CV determination or volume metering at entry to charging areas. Although it may be possible to achieve better accuracy with modern CV determination instrumentation, the overall impact on consumer billing would be insignificant.

There is in fact some merit in relaxing accuracy standards for CV determination or volume metering at entry to charging areas if this could open up lower capex/opex options for CV measurement instrumentation, such as micro-gc or inferential devices. This approach would be especially applicable for low volume flows such as inter-LDZ flows, small NTS offtakes and injection of biomethane and other non-conventional sources of gas. As might be expected, the impact of such slight changes in accuracy of FWACV on the domestic consumer energy bill is also slight.

**Use of lower accuracy CV determination devices, e.g. a(E(CV)) of ±0.5 MJ/m$^3$, for daily volume flows of up to around 2.5 million m$^3$ would therefore have an almost imperceptible impact on accuracy of FWACV and on accuracy of consumer energy billing.**

A key assumption in this study was that for flows into the charging area the CV and flow measurements were unbiased, i.e., the distribution of errors was centred at zero. In practice individual instruments will demonstrate some bias and for gas chromatographs will reflect how well the composition of the calibration standard employed matches the distribution of compositions of gases that might be presented to individual instruments. An additional criterion for CV determination instrumentation is therefore recommended, based on the mean error in CV for the gases likely to be (or actually) presented to the instrument. (The MPE is based any possible gas composition within the approval range of the instrument.)

## 6.3 LDZ ENERGY

For a typical LDZ, where uncertainty in bias in NTS offtake metering and CV determination are around ±4% and ±0.1 MJ/m$^3$ respectively, determined LDZ energy is estimated to be zero and expanded uncertainty in bias estimated to be ±2.04%. Biomethane flows employing CVDDs with an accuracy of ±0.5 MJ/m$^3$ are not expected to have a material impact.

## 6.4 BLENDING

In some networks it may be possible for biomethane to be injected into a gas distribution system with either no or reduced enrichment if it can be demonstrated that:

(i) comingling of the biomethane with distributed gas resulted in a gas mixture with a CV that was sufficiently high to prevent the application of the 1 MJ/m3 cap in the FWACV, and

(ii) the biomethane was not conveyed to consumers before comingling. Note that in this situation the CV is determined solely to ensure the FWACV cap does not come into play and is not used in the calculation of FWACV itself.

Under this situation determination of the accuracy of the CVDD used to monitor the comingled mixture will dictate the target CV for successful comingling. The more accurate the device the closer the target CV can be set to FWACV- 1MJ/m$^3$ (and *vice versa*). The criterion for successful blending is:

$$[FWACV\text{-}CV_{mixture}] \leq 1 \text{ MJ/m}^3$$

The standard uncertainty in determined FWACV is typically 0.0746% or around 0.03MJ/m$^3$, so the expanded uncertainty in [FWACV-CV$_{mixture}$] is $\sqrt{(0.06^2 + 0.1^2)}$ = 0.117 MJ/m$^3$ using the currently approved CVDD. CV determination of the comingled mixture would therefore have to demonstrate that [$FWACV-CV_{mixture}$] ≤ 0.883 $MJ/m^3$ in order to demonstrate the requirement had been met at the 95% probability level. The Table below shows how using lower accuracy CVDDs would require comingled CV to be closer to FWACV.

Table 5: CV targets for comingled gas for CVDDs of differing accuracy

| CVDD MPE, $MJ/m^3$ | U($FWACV-CV_{mixture}$), $MJ/m^3$ | Maximum value of [$FWACV-CV_{mixture}$] $MJ/m^3$ |
|---|---|---|
| 0.1 | 0.117 | 0.883 |
| 0.2 | 0.209 | 0.791 |
| 0.5 | 0.504 | 0.496 |

In practice the FWACV will not be known in advance and the target CV of the comingled gas will need to be based on an estimate of FWACV, so some allowance will be needed to account for the uncertainty in the estimate of the FWACV.

## 6.5 TYPE APPROVAL OF CVDDS

The present framework of approval of CVDDs for CV measurement sites directed by Ofgem consists of Ofgem commissioning testing of a potential device by Ofgem's technical services provider on receipt of a request from one or more Gas Transporter. If the results of testing are acceptable Ofgem will issue a Letter of Direction to the Gas Transporter requesting approval of the device. Arguably, there are a number of drawbacks to this approach:

a) There is no published specification detailing the performance and functionality required of a CVDD. Custom and practice would suggest that an MPE of ±0.1 $MJ/m^3$ is currently required.

b) Testing can only be initiated at the request of a Gas Transporter – not CVDD suppliers, gas producers or DFOs.

c) Testing is performed by a single service supplier.

A more open framework for type approval of CVDDs in which required performance is clearly specified could minimise commercial uncertainty for potential CVDD suppliers. Cost of testing could be optimised by opening testing services to multiple testing laboratories. Rigour of testing could be ensured, or even improved, by use of laboratories accredited to ISO 10725 (in the UK this would mean UKAS-accredited laboratories).

A suggested framework for testing of CVDDs is as follows:

a) A specification for the performance and functionality of CVDDs is published by Ofgem and could be made available of the Ofgem website. The specification should cover performance (which could concisely be specified as required MPE and MPB in gross calorific value) and functionality (which would specify Ofgem's requirements such as calculation of gross calorific value to ISO 6976, UK reference conditions, data storage requirements, action in event of power failure, etc.).

b) Testing against Ofgem's specification by any laboratory that is accredited to ISO 10725 for certification of instruments against a specification. In the UK this would mean UKAS accreditation for this specific purpose. The outcome of such testing would be a testing report and certificate indicating: mean error, uncertainty in mean error and whether the required functionality was present in the CVDD. The certificate would also give an opinion on whether the device met the requirements of Ofgem's specification. The use of accredited laboratories would add metrological rigour to the testing and subsequent opinion.

c) Testing would be carried out at the request of any appropriate body (CVDD supplier, gas producer, gas transporter, Ofgem) and cost of testing paid by the requesting party using normal commercial arrangements.

d) Request to Ofgem to consider formal approval based on the testing report and certificate would come from the party that is directed by Ofgem to determine CV. At present this is solely the Gas Transporter; but if changes to the Regulations are envisaged, other parties could be directed.

e) Formal approval of CVDDs, together with any limitations in applicability if appropriate, could be granted by Ofgem after consideration of the testing report and certificate from the testing laboratory. Such formal approval could be issued through the existing Letter of Approval to the party that is directed to determine CV, so no change in legislation would be required.

## 7 CONCLUSIONS

1) For a typical LDZ, where uncertainty in bias in NTS offtake metering and CV determination are around ±4% and ±0.1 MJ/m3 respectively, the bias in domestic energy metering is estimated to be: -0.445% ±7.42%. The dominant sources of bias and uncertainty in bias are associated with fixed factors for conversion of actual domestic metered volume to reference temperature and pressure.
2) For a typical LDZ, the bias in LDZ energy is estimated to be: 0% ±2.04%. The bias in LDZ energy resulting from the LDZ model is zero because the model assumes that daily volumes and daily CVs are unbiased.
3) Current custom and practice is for Ofgem to require that (absolute) error in CV measured by CV determination equipment should not exceed 0.10 $MJ/m^3$. This requirement results in insignificant impact on domestic energy metering.
4) Some relaxation in Maximum Permissible Error (MPE) in CV determination may be appropriate, particularly in low volume applications, such as biomethane injection, for which the anticipated daily volumes are so low as to make CV determination accuracy insignificant in respect of impact on the domestic consumer. The appropriate MPE should be decided by consideration of other regulatory issues (such as monitoring of compliance with the GS(M)R if shared duty is being practiced), or normal commercial factors for sale of energy. However, daily flows of up to 2.5 million $m^3$ could be measured with devices having an MPE of ±0.5 $MJ/m^3$ with no material impact on accuracy of FWACV and hence domestic consumer energy billing.
5) In addition to MPE, a formal performance specification for CV determination devices should include a maximum bias shown by CV determination devices with gases that the instrument (or family of instruments) is likely to see.
6) Accuracy of CV determination of comingled mixtures will dictate how far from the FWACV the CV of the comingled gas can be allowed to deviate. Lower accuracy CVDDs will require CV of the comingled gas to be stay relatively close to the anticipated FWACV.

## RECOMMENDATION

1) CV determination devices with a maximum permissible error of ±0.5 $MJ/m^3$ are recommended for all credible flows of biomethane into gas distribution systems.
2) A framework for type approval of CVDDs is recommended. The salient features of such a framework are set out in the report.