FUTURE BILLING METHODOLOGY

MS13 FBM Report on Novel Validation of Network Modelling for Embedded and Network Charging Areas

Cadent Gas Ltd

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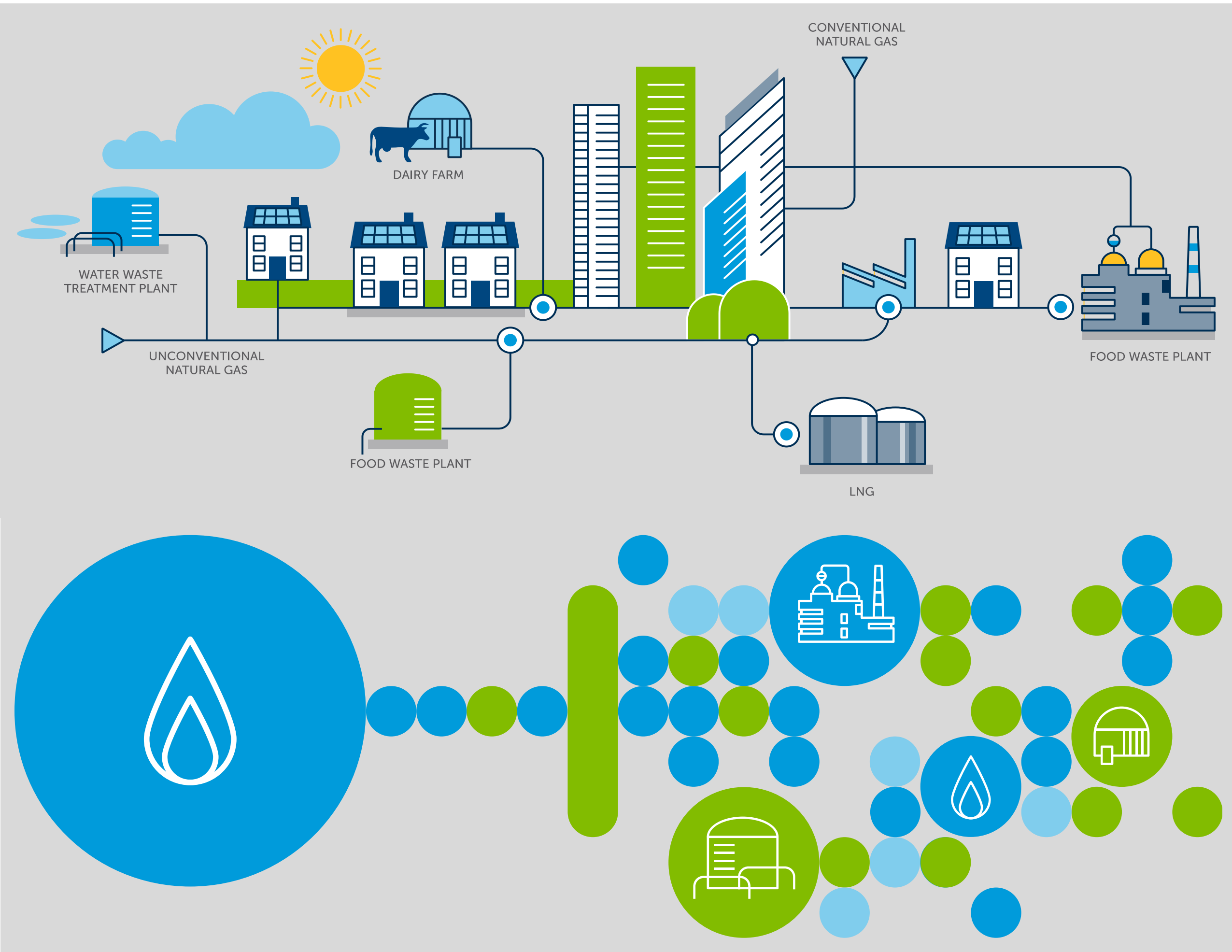

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Objective:

The Future Billing Methodology Project is a Proof-of-Concept which explores options for a fair and equitable billing methodology for the gas industry which will be fit-for-purpose in a lower-carbon future. This report covers the analysis and application of the FBM field trial data that was gathered.

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1 EXECUTIVE SUMMARY

1.1 The FBM Project

The Future Billing Methodology Project (FBM) is a Proof-of-Concept which explores options for a fair and equitable billing methodology for the gas industry which will be fit-for-purpose in a lower-carbon future. It aims to integrate diverse gas sources without needing to standardise energy content by means of enrichment or ballasting[1] and will inform the industry on potential billing options to support decarbonising the GB gas networks and open the pathway towards a net-zero carbon heat future.

1.2 FBM Field Trials

The FBM Project field trials installed a range of sensors at strategic locations in local gas networks around two embedded biomethane input points in separate networks within the East of England. The purpose was to compare empirical field measurements with network modelling outputs to demonstrate that network models can reliably simulate the travel and mixing of gases across the network, and hence could be used to determine Calorific Value (CV) zones for billing purposes. Biomethane sites were used for this study as that is what is presently available for conducting a gas tracking network model validation exercise, but the learning from the field trial and the capability of network modelling has wider application across the range of decarbonisation initiatives being explored by the gas industry, including hydrogen blending.

As the enrichment of low-CV gases with propane cannot be turned off without triggering the LDZ FWACV cap[2], molecular oxygen sensors were used to track the presence of biomethane, as the typical oxygen content of biomethane is significantly higher (around 0.2% mol./2,000 ppm in this trial) than in gas from the National Transmission System (NTS) (typical upper limit 0.001% mol./10ppm). Further information on sensor settings and testing is provided in Section 3 of this report and Section 4 of the MS12 Final Report on Field Trial Progress.

1.3 Report Summary

1.3.1 General

This report covers the analysis and application of the FBM field trial data gathered at measurement points in each network. It provides a description of the travel of the biomethane from embedded input points within the two test networks and compares the data with the network analysis model results over a corresponding range of demand levels. The application of network modelling techniques shows how the models can be used to identify the zone of influence exerted by the embedded supply and how the zone of influence behaves under varying demand conditions.

Network analysis modelling software tools have been used to simulate the movement of the gas through the networks. The more detailed analytical and modelling work has focused on the field trial area around Cambridge as the Synergi Gas software used for this network currently has the functionality to track a component of the gas along with the CV. For Lincolnshire, the GBNA[3] software used for this network is currently able to show the mixing of different sources but not the CV of the gas.

Having demonstrated consistency between sensor gas tracking and network modelling, the network model functionality is then used to model gas mixing and gas CV variation across the Cambridge network over the

[1] The present billing regime sets each of the 13 Local Distribution Zones as a charging area. Within each charging area the energy content (calorific value or CV) of gas entering it must be standardised to within a tolerance of no more than 1 mega joule per cubic metre between highest and lowest CV sources. Low-CV gases are presently enriched using high-carbon propane. Alternatively, high-CV gases may be ballasted with nitrogen to reduce the CV. (See further detail in Section 2 of the main report for further detail.)

[2] The LDZ FWACV cap sets the allowed flow-weighted average CV of gas in each charging area at no more than 1 mega joule per cubic metre (1 MJ/m^3) above the lowest source CV. If triggered by out-of-tolerance gas, this cap protects gas customers from over-billing, but very small out-of-tolerance volumes can cause a disproportionate misallocation between billing and shrinkage costs which are passed back to System Users. (See Section 2 of this report,)

[3] Additional CV tracking functionality to provide CV results to the user is on the GBNA development roadmap.

observed demand range, with and without enrichment of the biomethane. A case study analyses the annualised consumer bill impact of the CV variations, which indicates that it is possible to configure a low-CV Charging Area around the embedded supply. Further detail is provided in the following summary paragraphs and the main report provides a deep-dive into the field trial and analytical work.

1.3.2 Tracking of Oxygen and Network Modelling

The image below is a geographic view of the measured oxygen sensor readings (circles) at a specific time of 18:00 on 27th October at a time of higher demand, in the Cambridge gas network, with modelled oxygen values overlaid along the course of the gas pipelines for the same time. Darker colouring of both the sensors and pipes represents higher oxygen concentration (higher levels of biomethane). Viewing the measured and modelled values together (Figure 1) it can be seen that the modelled zone of the concentration of oxygen is comparable with the point measurements (further detail in Section 6).

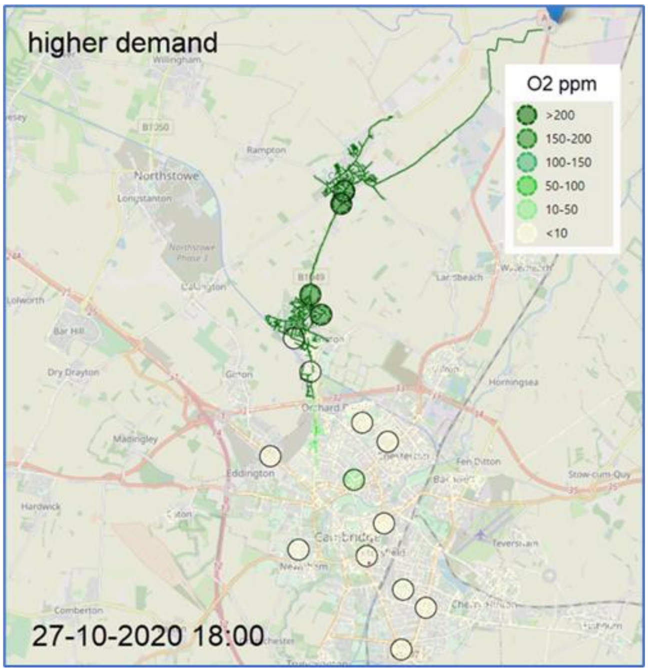

Figure 1 - Measured Oxygen Readings (circle) and Modelled Oxygen Values; Higher Demand Example

The network modelling compares closely with the measured oxygen data and shows that gas from the biomethane sites travels through the local gas network, with the distance travelled being linked to the level of network demand, biomethane flows and network dynamics. These results are in line with expectations, given that the biomethane plants studied deliver gas at a relatively constant flow rate into the network.

As network demand reduces, the biomethane travels further into the network to be used by consumers. Figure 2 compares the data at 3:30am on 27th July, a time of lower demand.

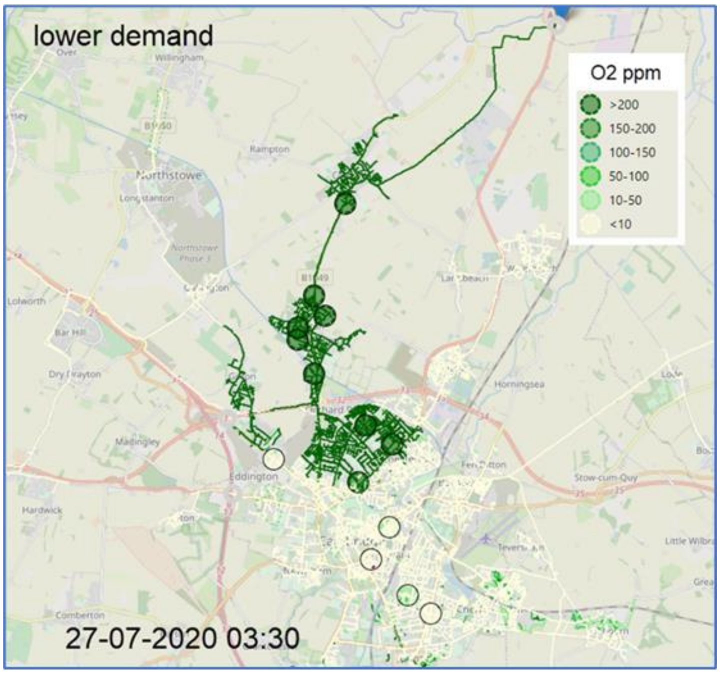

Figure 2 – Measured Oxygen Readings (circle) and Modelled Oxygen Values; Lower Demand Example

However, further analysis shows that due to the relatively stable input volumes, the wider penetration of biomethane at low demand is transient and would have minimal impact on consumer bills. Whilst this would not be true for an input point which flexes gas volume injected in line with demand, network modelling would be able to account for such variability, given the appropriate inputs.

The network modelling has been shown to be highly accurate for the majority of the biomethane range, but is slightly conservative in predicting its reach. These results provide confidence that for the vast majority of the biomethane-affected area; results from the model accurately reflect reality in terms of the presence or absence of biomethane. For the very low oxygen concentration levels, where the network modelling was less accurate, the impact of the biomethane on the CV of the mixed gas would be negligible.

1.3.3 Network Modelling of Sources with Differing CVs

Having demonstrated that the network models used by GDNs can reliably predict the penetration of gas into the network, this report also demonstrates that the functionality of the network analysis software can reliably simulate how the CV of gas varies across a network over a range of demand levels. Figure 3 below shows the same network analysis model being used to model gases with sources of differing CVs, simulating gas travel and mixing under the same demand conditions if propane enrichment were removed from the Chittering biomethane plant into the Cambridge network (further detail in Section 7).

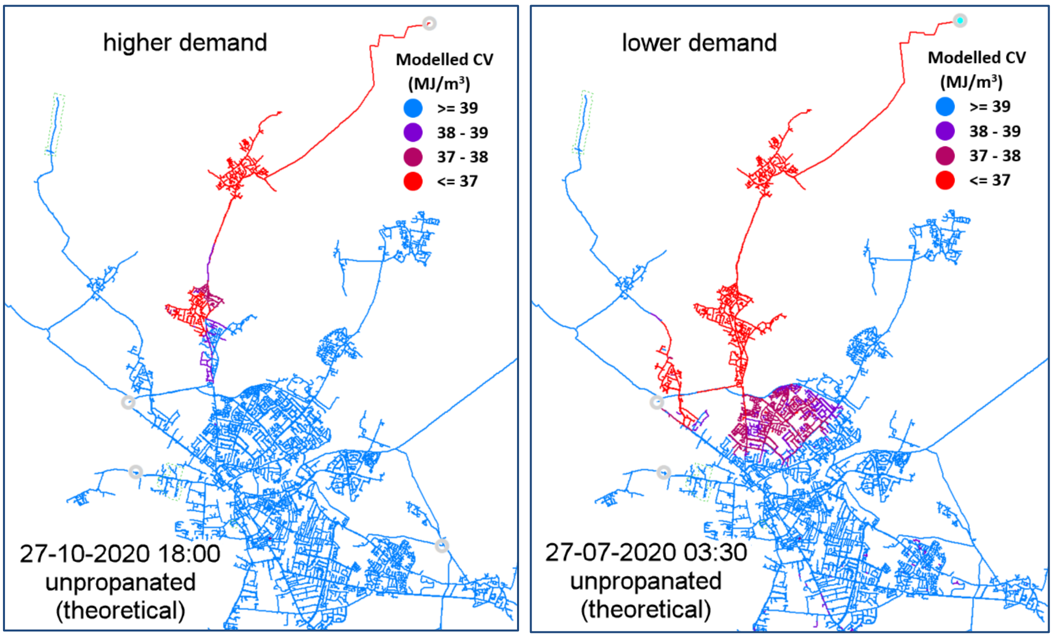

Figure 3 – Examples of CV Modelling with Propane Enrichment Removed

1.3.4 The Original FBM Options

The original FBM NIC submission contained three conceptual future billing options:

1. **Pragmatic Option –** Envisaged using network modelling to determine Charging Areas around low/high-CV embedded entry points, sized such that consumers within the low-CV zone, billed on that entry CV and others outside that area, billed on the LDZ FWACV (excluding the low-CV entry) are neither advantaged nor disadvantaged to a greater extent than would be the case under the existing FWACV regime. This option would not require any additional CV measurement to be installed.

2. **Composite Option –** Proposed as an evolutionary extension of "Pragmatic" would principally use network modelling to configure Charging Areas around each input point to the LDZ, whether these are Offtakes from the NTS or embedded entry points. This would also consider areas of the LDZ that could be isolated for billing purposes, e.g., single-feed sub-networks could potentially use an additional CV measurement device installed at an appropriate pressure reduction station (PRS) for billing downstream consumers. This option could require moderate to significant investment in "within-network" CV measurement devices, depending on LDZ size and system configuration.

3. **Ideal Option –** A further development on "Composite" in which every consumer is billed based on the CV of gas measured locally to the point of use, such that the energy used and billed for are the same. This option would require very significant investment in CV measurement devices local to the point of use. A potential additional feature of the Ideal option would be transmission of CV data from local measurement points to customers' smart meters to enable a further transition to full gas energy metering & billing at the point of use (this latter point is the subject of the MS11 Smart Metering Laboratory Trials Report).

1.3.5 Methods for Defining a Charging Area

The FBM project focuses on potential solutions that would enable low carbon gases into the network, such as biomethane or blended hydrogen, without the need for enrichment, subject to changes to GS(M)R. Two of the three original FBM billing options (Pragmatic and Composite) are based wholly or partly on using network analysis models to create Charging Areas within the LDZ for billing purposes.

The analytical work in this report shows firm comparisons can be made between the field trial measurements and the low-CV area predicted by the network analysis model. These comparisons provide evidence that the example network model could also be suitable for use in defining an embedded low-CV Charging Area.

The focus for FBM modelling has been to develop a Charging Area methodology that is:

- straightforward to define,
- simple to implement,
- and equitable to consumers on the network.

One of the key NIC objectives was to work within the current Gas (Calculation of Thermal Energy) Regulations of requiring allocation to a CV Determining Device (CVDD) when defining a Charging Area. The option to use a modelled CV for billing purposes has also been explored in this report, but may require a review of the Gas (Calculation of Thermal Energy) Regulations.

This report has developed, at a high-level, possible methods for identifying Charging Areas for further exploration including industry consultation, to begin unlocking the decarbonisation of GB's existing gas networks and maintaining an equitable billing outcome for consumers. Fundamental to each option is that all Supply Meter Points (SMPs) are allocated an individual billing CV. SMPs may be grouped together and assigned to the same CVDD or modelled CV, but there is an underlying assumption that billing CVs are assigned at SMP level.

The methods are detailed below, with the first 3 aligned to the original NIC options and the fourth method that has evolved with the project. In summary:

- Options 1 and 2 require network modelling to assign a consumer to a Charging Area
- Option 3 requires limited network modelling to determine the most appropriate position of the within network CV measurement
- Options 1, 2 and 3 use measured CVs for consumer billing
- Option 4 uses measured CVs as an input for network modelling which generates a modelled CV for consumer billing.

1.3.5.1 Option 1 Pragmatic – Identify Charging Area through Annual Use Analysis

Network CV modelling and consumer annual use profiles are used to generate a financial "typical consumer bill" analysis. All SMPs within the identified low-CV Charging Area would be assigned to the low-CV CVDD, while all others would be assigned to the LDZ FWACV. This method of defining Charging Areas around existing embedded inputs, such as biomethane entry points, is in the manner envisaged by the original FBM Pragmatic option. While the worked example (8.2.1) has focused on a typical domestic consumer, it has also been developed to look at the financial implications on non-domestic consumers. This method can be equally applied to a high-CV embedded entry.

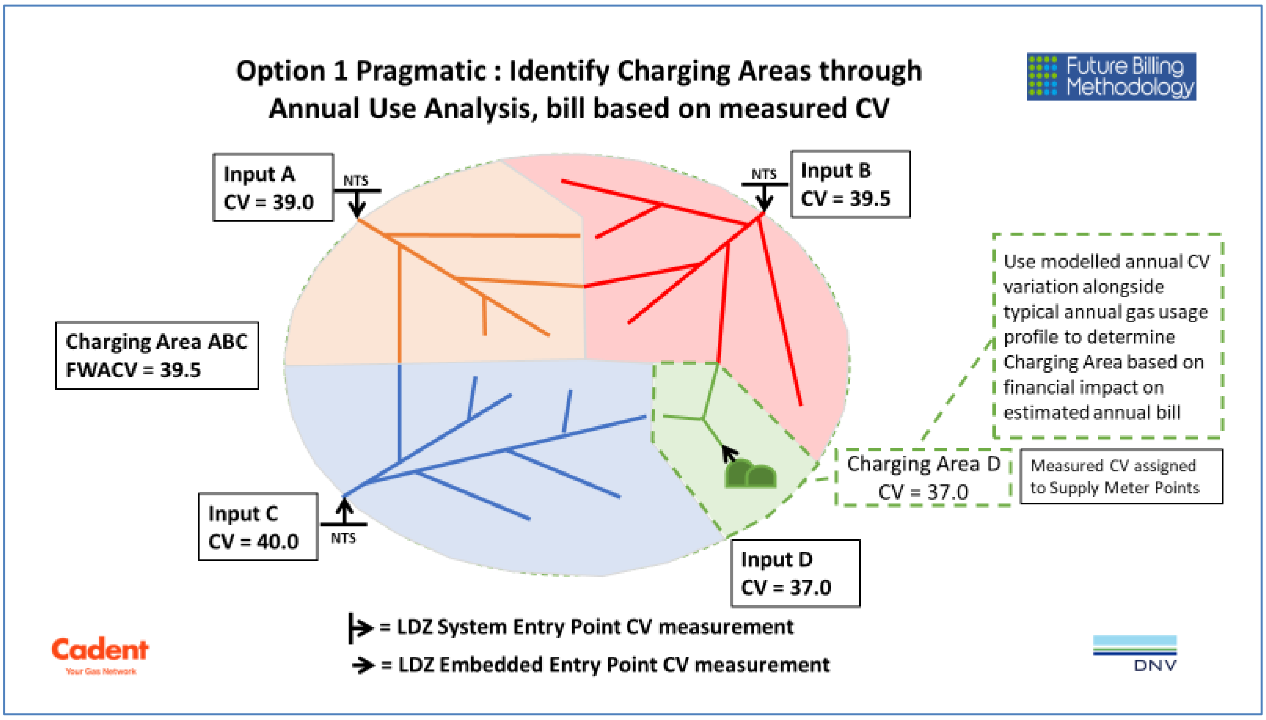

Figure 4 - Option 1 Pragmatic – Identify Charging Areas through Annual Use Analysis

1.3.5.2 Option 2 Composite – Separate Charging Areas for Supplies into the LDZ

This option uses network modelling to configure Charging Areas around each input point to the LDZ, whether these are Offtakes from the NTS or embedded entry points. This would also consider areas of the LDZ that could be isolated for billing purposes, e.g., single-feed sub-networks could potentially use an additional CV measurement device installed at an appropriate pressure reduction station (PRS) for billing downstream consumers. This option could require moderate to significant investment in “within-network” CV measurement devices, depending on LDZ size and system configuration.

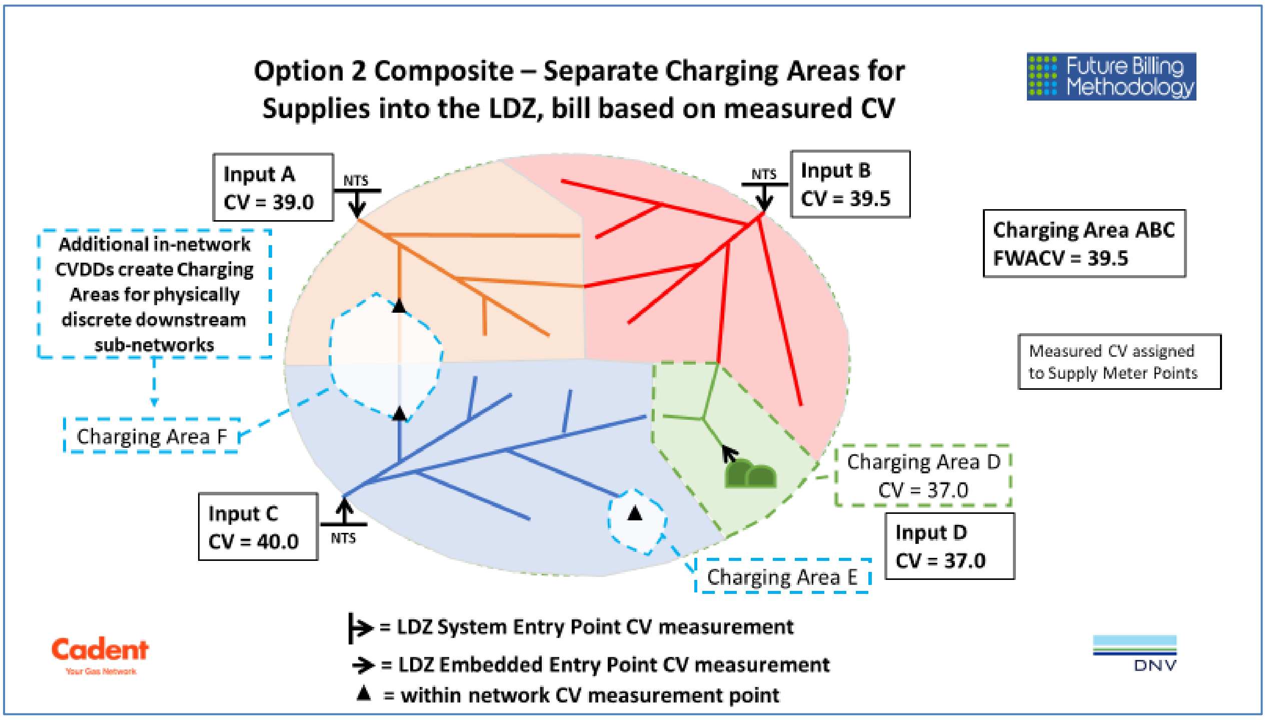

Figure 5 - Option 2 Composite– Separate Charging Areas for Supplies into the LDZ

1.3.5.3 Option 3 Ideal – Local CV Measurement Charging Areas

Originally this method considered the transmission of CV data from local measurement points to customers' smart meters to enable a further transition to full gas energy metering & billing at the point of use (this latter point is the subject of the MS11 Smart Metering Laboratory Trials Report).

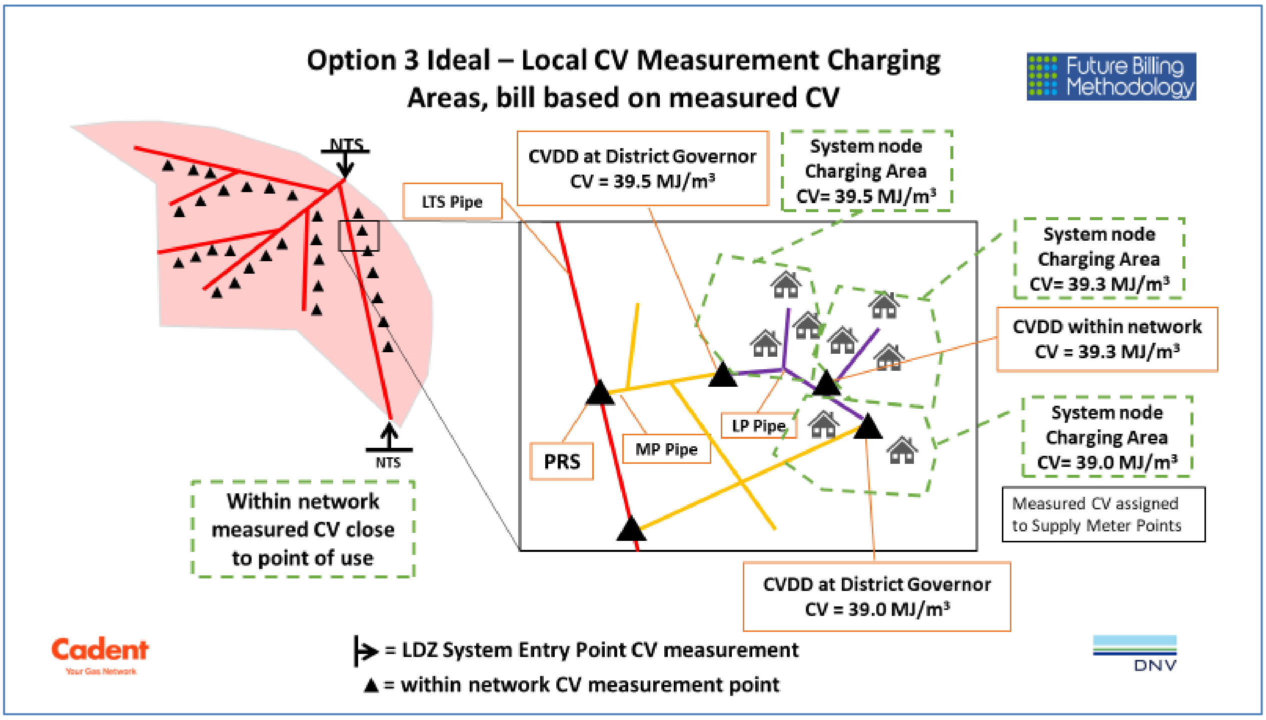

Figure - 6 Option 3 Ideal – Local CV Measurement Charging Areas

The key findings from the MS11 Smart Metering Laboratory Trials Report were that the capability exists, in principle, to deliver locally-derived calorific value data to gas smart meters (GSME), and to convert this to a kWh value which could then be used for direct billing purposes. However, a number of technical challenges/limitations including, though not limited to, meter battery life, data reading traffic load and metering specifications for kWh retrieval, require further exploration and understanding.

1.3.5.4 Option 4 - Modelled CV for Consumer Billing using Online LTS model

During the development of this project, specifically the network modelling aspects, a fourth concept for defining Charging Areas has evolved. In contrast to the above three methods, this approach would generate a modelled CV for billing purposes.

This approach would use online network modelling of the LTS along with SCADA data to provide continually updated values of modelled CVs received at both individual LTS PRSs into the lower pressure tiers and direct LTS-connected consumers. This would combine the measured CV values along with measured pressures and flows to calculate the CV at defined periods of time, for example hourly or daily, delivered by the LTS.

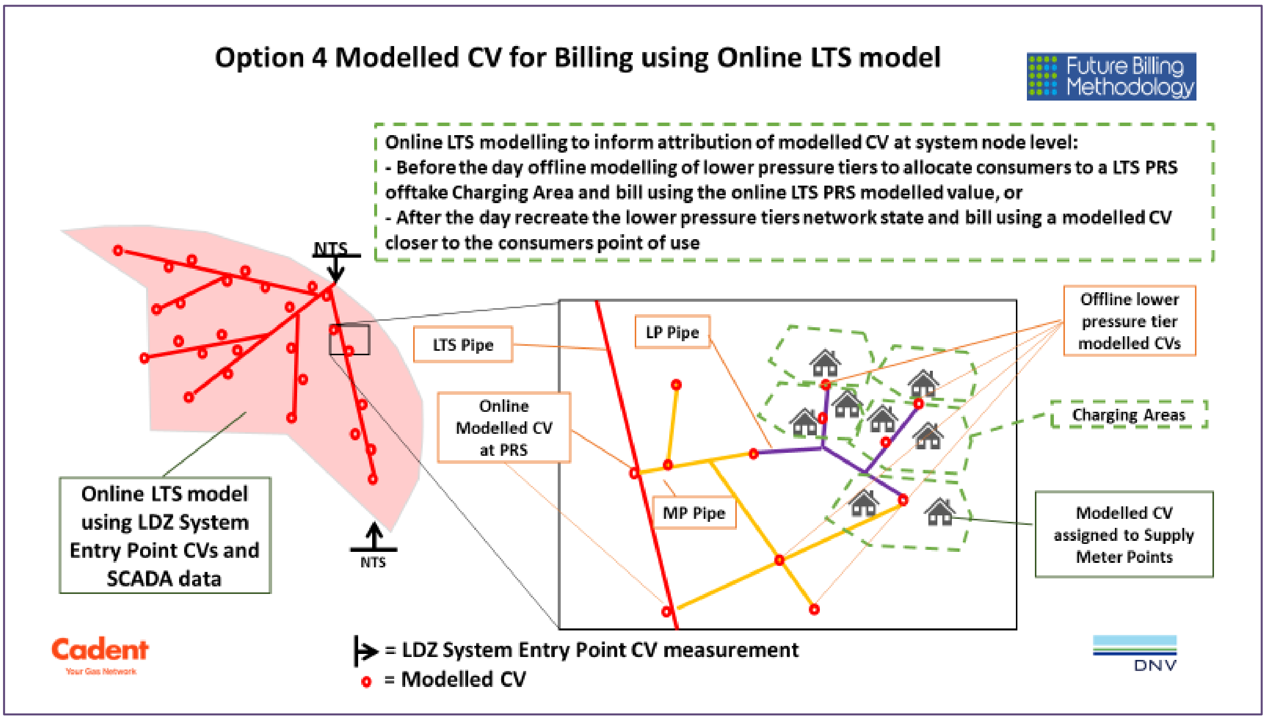

Figure - 7 Option 4 Modelled CV for Billing using Online LTS Network Modelling

For pressure tiers downstream of the LTS, the allocation of a billing CV could either be done through:

- Undertaking upfront offline modelling of lower pressure tiers to allocate consumers to a Charging Area. All consumers within the downstream pressure tier networks would be assigned to a LTS PRS for billing purposes and the billing CV would be provided by the online system. In instances where there is mixing of gas on the lower pressure tiers with other gases of different CVs, this would require additional downstream CV modelling such as the methods described above for the Pragmatic Option.
- Recreating the lower pressure tiers network state after the day using the CVs from the modelling of the LTS as an input to the downstream pressure tier models. In this case, each network analysis model system node would become a Charging Area in its own right. All SMPs within the network would be assigned a billing CV based on the after the day network analysis modelled CV value for the system node to which they are assigned. This method of defining Charging Areas, is similar to that envisaged by the original FBM Ideal option, with the exclusion of smart metering, replaced with a modelled CV value local to the point of use.

If feasible, either approach to a modelled CV could provide both the benefits sought by the Pragmatic option and provide a consistent methodological pathway to facilitate hydrogen blending at higher tiers of the gas distribution network, and the transition to pure hydrogen, wherever this is practicable.

1.3.5.5 Options Summary Table with Initial High-Level Cost Analysis

Table 1 below summarises the FBM Project billing options and advantages / disadvantages of each option to aid the industry consultation on the way forward. It provides a condensed view of the different approaches, to allow a simple comparison between them when read across the table, or a list of pros and cons for an individual approach when read down the table. A more detailed understanding behind the pros and cons can be gained from the body of the main document.

This technical report has assumed that system architecture, Network Code changes, system requirements for Xoserve, Shippers and Suppliers etc. is the same for each option so related advantages and disadvantages have not been included in the table.

For each method, a high-level indication of the costs have been included. This information has been based on the Cost Benefit Analysis undertaken for the Ofgem Stage-gate in 2017[4]. These figures are to be updated for the CBA in the FBM final project report, but give an indication of the order of magnitude of the possible costs involved with each method. The original CBA also provided a monetised view on the potential carbon savings gained through the implementation of FBM. This will also be updated for the final project report CBA.

[4] Included within the report NIC04 – Project Progress Report 1 December 2017; https://futurebillingmethodology.co.uk/wp-content/uploads/2017/12/FBM-Project-Progress-Report-Final-v2.pdf

	Methods for Defining a Charging Area				
	Measured CV applied to Consumer Billing			**Modelled CVs applied to Consumer Billing**	
	1 - Pragmatic	**2 - Composite**	**3 - Ideal**	**4 - Modelled CV for Billing using Online LTS Model**	
				(A) Before the Day	**(B) After the Day**
Method Summary	• Applies to specific input points e.g. embedded entry sites. • Network modelling & financial analysis used to generate embedded charging area • Customers billed on measured CV at input to charging area or FWACV of parent LDZ accordingly	• Network analysis informs tactical location of CVDDs within the network • CVDDs attribute CV for billing within sub-LDZ charging areas	• CVDDs located throughout network to measure CV for billing close to point of use	• Use measured CV and flows at LDZ system entry as inputs to modelling. • Use of online modelling of LTS to derive a CV value at each LTS exit point. • Predictive modelling of downstream networks to create charging areas for each LTS exit point	• Use measured CV and flows at LDZ system entry as inputs to modelling. • After-the-day reconstruction of the network state to generate output CV values for each meter point
Advantages	• Upfront analysis of the network models	• Upfront analysis of the network models	• Upfront analysis of the network models	• Upfront analysis of the below LTS network models	
	• Applicable to low and high CV embedded entry and embedded hydrogen blending	• Applicable to low and high CV embedded entry and H2 blends	• Applicable to low and high CV embedded entry and H2 blends	• Applicable to low and high CV embedded entry and H2 blends	• Applicable to low and high CV embedded entry and H2 blends
	• Fixed allocation of SMPs to Charging Area; annual or periodic re-assessment of Charging Areas	• Fixed allocation of SMP to Charging Area; annual or periodic re-assessment of Charging Areas	• Most equitable approach for Consumer billing as the CV is measured close to the point of use	• Fixed allocation of SMP to Charging Area; annual or periodic re-assessment of Charging Areas	• Most equitable approach for Consumer billing as the CV is modelled close to the point of use
	• Can be undertaken with existing network modelling software	• Can be undertaken with existing modelling software	• Can be undertaken with existing modelling software		
	• Consumer Billing CV would be a measured value from a CVDD closer to point of use	• Consumer Billing CV would be a measured value from a CVDD more local to point of use	• Consumer Billing CV would be a measured value from a CVDD very close to point of use	• Consumer Billing CV would be a modelled value for the relevant LTS exit point, closer to the point of use	• Consumer Billing CV would be a modelled value very close to the point of use

	Methods for Defining a Charging Area				
	Measured CV applied to Consumer Billing			**Modelled CVs applied to Consumer Billing**	
	1 - Pragmatic	**2 - Composite**	**3 - Ideal**	**4 - Modelled CV for Billing using Online LTS Model**	
				(A) Before the Day	**(B) After the Day**
Advantages	• Embedded Charging Area is determined by network modelling to predict CV at each system node throughout the review period, then analysing bill impact on one typified customer at each node on the relevant network. • Annual use analysis is theoretically the most equitable method for customers. (Alternatives in Appendix D.)	• Charging areas determined by predictive network modelling. • Billing CV provided by tactically-located CVDDs upstream of each Charging Area	• Charging Areas highly localised.	• Measured CVs used to generate a modelled billing CV for each downstream Charging Area based upon continually updated online LTS modelling	• Measured CVs used to generate a modelled billing CV at system node level based upon continually updated online LTS modelling
				• Modelling CV across the LDZ for billing would be cheaper and 'greener' than the installation of a large number of physical CVDDs (assuming existing technology)	• Modelling CV across the LDZ for billing would be cheaper and 'greener' than the installation of a large number of physical CVDDs (assuming existing technology)
			• Consistent platform for handling the full transition to gas decarbonisation	• Consistent platform for handling the full transition to gas decarbonisation	• Consistent platform for handling the full transition to gas decarbonisation
				• Existing commonality of node names on LTS and Gemini system	• Existing commonality of node names on LTS and Gemini system
Disadvantages	• Fixed Charging Area that assumes minimal changes in network / demand dynamics	• Fixed Charging Area that assumes minimal changes to physical network / demand dynamics		• Fixed Charging Area on the below LTS system that assumes minimal changes in network / demand dynamics	
	• Risk that actual variations in input CV and network state may differ from when the Charging Area is created	• Risk that the variable network state on the LTS may not be taken into account when the Charging Area is created		• Risk that the variable network state on the LTS is not taken into account when the Charging Area is created	

	Methods for Defining a Charging Area				
	Measured CV applied to Consumer Billing			**Modelled CVs applied to Consumer Billing**	
	1 - Pragmatic	**2 - Composite**	**3 - Ideal**	**4 - Modelled CV for Billing using Online LTS Model**	
				(A) Before the Day	**(B) After the Day**
Disadvantages	• Requires annual network demand profiles and energy use profiles for different consumer types	• Requires a consistent approach for complex upfront offline modelling to define Charging Areas below the LTS		• Requires a consistent approach for complex upfront offline modelling to define Charging Areas below the LTS	
		• Requires additional modelling to Pragmatic to create CV Charging Areas		• Requires additional modelling to Pragmatic to create CV Charging Areas	• Network modelling to create CV Charging Areas would be highly labour intensive, unless automated
	• Additional network analysis required compared to alternatives considered in Appendix D to generate Charging Area; could be mitigated through automation	• Additional network analysis required from NTS offtake down through the pressure tiers as well as steady state modelling of lower tiers		• Additional network analysis required from NTS offtake down through the pressure tiers as well as steady state modelling of the lower pressure tiers	• Complex network modelling to recreate the LDZ network-state after the day to generate the billing CV by network node / meter point
		• Cost of installation, powering and maintenance of ~10,000 additional CVDD equipment units	• Cost of installation, powering and maintenance of ~44,000 additional CVDD equipment units		
		• Assuming current technology - emissions from additional CVDD venting up to 130 ktCO2e; CoC ~£9.2m per year.	• Assuming current technology - emissions from additional CVDD venting up to 580 ktCO2e; CoC ~£40.6m per year.		
			• Technical challenges/limitations of assigning a CV to a smart meter		
				• Requires implementation of suitable LTS online software	• Requires implementation of suitable LTS online software
				• Consumer Billing CV is not from a measured CVDD	• Consumer Billing CV is not from a measured CVDD
					• Highly system intensive

	Methods for Defining a Charging Area				
	Measured CV applied to Consumer Billing			Modelled CVs applied to Consumer Billing	
				4 - Modelled CV for Billing using Online LTS Model	
	1 - Pragmatic	2 - Composite	3 - Ideal	(A) Before the Day	(B) After the Day
Disadvantages					• Significant amount of network related data required to recreate the LDZ network-state on a daily basis
	Early High Level Indicative Costs (Based on 2017 Initial CBA)				
CAPEX £m	£58.0m	£393.9m	£799.1m	£81.3m	£81.3m
OPEX (Set-up) £m	£0.3m	£1.2m	£3.3m	£1.2m	£3.3m
OPEX (Ongoing) £m	£2.4m	£6.9m	£12.8m	£4.5m	£5.3m

Table 1 – FBM Options Summary Table with Initial High-Level Cost Analysis

1.4 Conclusions

This report has built on the work carried out by Cadent and DNV in identifying and installing a range of flow, oxygen, pressure and CV sensors in the Cambridge and Lincolnshire networks. Despite the technical and site-specific issues and the impact of the Covid-19 pandemic encountered during the installation phase which limited the data gathering period of the sites, the body of data obtained provides a representative base for seasonal effects to be analysed.

DNV have drawn the following conclusions:

Network Analysis Modelling

It has been demonstrated that network modelling – which already performs a critical planning & design role underpinning safety and security of supply – can closely simulate how the network performs under varying demand conditions. The existing network model of Cambridge is able to simulate the variation of CV of gas in the Cambridge network at different demand levels over a year. A Charging Area could be developed around such an embedded source of gas, which would remove the need for enrichment and could constrain billing disparities to within the range experienced under the existing LDZ FWACV regime.

The network modelling has been shown to be highly accurate for the material extent of the biomethane range but is slightly conservative in predicting its reach. These results provide confidence that the model can accurately reflect reality in terms of the presence / absence or concentration of biomethane gas across the network. For the very low oxygen concentration levels, where the network modelling was less accurate, the impact of the biomethane on the CV of the mixed gas would be negligible. This strong correlation demonstrated between measured and modelled oxygen levels gives confidence that network modelling can accurately predict or simulate the travel and mixing of gases under varying demand conditions and, with appropriate software, can robustly attribute CV at system node level.

The report has developed, at a high-level, several methods for identifying Charging Areas for future billing purposes. This Proof-of-Concept Project is a key step along that pathway.

Charging Area Definition for a Future Billing Methodology

One of the key NIC objectives was to work within the current Gas (Calculation of Thermal Energy) Regulations requiring allocation to a physical CVDD when defining a Charging Area. However, at this point, there exists a range of views as to whether there is any scope within these regulations for the use of network modelling for Charging Area allocation. The following options all rely on network modelling to allocate a consumer to a Charging Area with their billing CV measured at a CVDD:

- Future Billing Option 1 Pragmatic – would use network CV modelling to determine an embedded Charging Area within the LDZ but would apply the existing CV measurement at the embedded gas source for billing consumers within that Charging Area. All other consumers would be billed on the LDZ FWACV.
- Future Billing Option 2 Composite – would use a combination of network CV modelling described for Option 1 Pragmatic and the identification of single fed sections of the LDZ to determine Charging Areas. These Charging Areas would require additional CV measurement for all consumer billing.
- Future Billing Option 3 Ideal – would use network modelling to determine the optimum location for CV measurement devices to be installed locally throughout the network. From these devices CV data could be transmitted to smart meters and/or to Smart DCC, so that the consumer could ultimately be billed directly on current gas energy use, rather than measured volume at an allocated CV.

Table 1 above shows that the additional CV measurement requirement within Options 2 and 3 would drive very significant capital and operating costs for the installation, powering, maintenance and replacement of CV measurement devices, and unless gas venting could be obviated by advances in technology, the levels of vented gas for CV measurement purposes would be unsupportable.

An alternative approach considered in this report is the use of measured CVs at the LDZ entry points combined with online network modelling of the LTS to generate modelled CVs for billing purposes.

- Future Billing Option (4) – Modelled CV, would use online LTS modelling with SCADA data to provide a continually updated values of modelled CV on the exit points from the LTS to the lower pressure tiers. This would combine the measured CV values along with measured pressures and flows to calculate the CV at defined periods of time, for example hourly or daily, delivered by the LTS. Allocation of a billing CV can either be done through:
    - Undertaking upfront offline modelling of lower pressure tiers to allocate consumers to a Charging Area assigned to a LTS offtake for billing purposes. The billing CV would be provided by the online LTS system.
    - Recreating the lower pressure tiers network state after the day using the CVs from the modelling of the LTS as one of the inputs to the downstream pressure tier models. In this case, each network analysis model system node would become a Charging Area in its own right and modelled CVs would be attributed to individual SMPs across the gas network.

Pathway to Decarbonisation

In the future there will be a wide range of gases introduced into the UK gas networks, including Hydrogen Blend and pure Hydrogen (physically separate network). Any future billing system would need to accommodate a number of different billing CVs and be able to assign groups of SMPs to a particular entry point. To enable fair and equitable billing across the gas supply chain under such a diversity of supply, the gas billing system architecture will require the capability to attribute an individual CV to each SMP for billing purposes. From the initial Stage-Gate of the FBM project, it was understood that SMPs could be assigned a billing CV different from the LDZ FWACV, reference XRN4323 - CV Zones (FBM) V1.8 AP .pdf from Xoserve. This understanding had guided the progression with the Charging Area definition options. More recent discussions with Xoserve have identified that significant system changes would be required to accommodate a number of different Charging Areas and to be able to assign groups of SMPs to a particular entry point for billing purposes.

Future transportation of pure hydrogen would effectively step over the transitional complexities of mixing gases of different CVs within the same pipeline network. In the mean-time and for those networks which would not ultimately transition to hydrogen gas distribution, the transition to net zero will require sections of networks and / or discrete networks to be shared by gases of differing CVs. For example, hydrogen blending at LDZ input points, sectorised parts of networks during conversion to hydrogen, partially or exclusively fed local biomethane networks with differing CVs. CV attribution at SMP level would be able to support the range of transitional arrangements, including transition to full hydrogen transportation where practicable, and longer-term diversity of gas supply for those networks that do not convert to hydrogen. It is understood that the current billing systems do not have this capability and therefore new functionality would be required whatever future billing option is taken forward.

Given the pressing need to decarbonise heat, the primary focus must be to identify the most appropriate and sustainable option for future gas billing which will include essential systems architecture changes to allow individual SMP billing CVs and may require an amendment to the Gas (Calculations of Thermal Energy) Regulations. In making the following recommendations, it has been assumed that for each Charging Area option the same system architecture, Network Code changes, system requirements by Xoserve, Shippers and Suppliers etc will be required.

1.5 Recommendations

As detailed in Table 1, each of the methods for defining a Charging Area offers different ways of delivering a future billing methodology, with varying levels of precision, complexity in implementation and overall cost.

In assessing the feasibility of Option 1 Pragmatic, it is acknowledged that Cambridge and Lincolnshire networks are examples of an integrated and a more geographically spread network respectively. The basic principles for Charging Areas for these networks have been set out and learning from this project has shown that it may not be possible to create a simple procedure that would apply to every network without understanding the operational issues particular to that network and the embedded entry points' operational requirements and control modes, see Section 9 for further detail.

It is recommended that models of several other networks with embedded entries (biomethane and potential hydrogen blend) be investigated to assess whether a robust Charging Area could be defined using Option 1 Pragmatic; annual use analysis or the alternative Pragmatic approaches discussed in Appendix D. Aspects that should be considered include but are not limited to the following:

- Stability / variability of embedded gas entry point supplies,
- Proximity of large and very large users to the embedded supply,
- Sensitivity analysis of input parameters to Charging Area boundary definition,
- Appropriate frequency of billing zone determination and update,
- A review of non-domestic energy profiles used in network modelling,
- The potential for the development of an automated system for aspects of the network analysis.
- Default and correction mechanisms for new sites or unforeseen changes in network flows.

It is recognised that in certain instances if the CV impacted Charging Area is not relatively static or easy to define, the Pragmatic approach may not be suitable for a selected embedded entry. However, the application of Option 1 Pragmatic should be further investigated for feasibility, considering factors listed above, as this approach could fulfil a transitional role and may bring earlier benefits for some embedded renewable-source gas supplies, while a full end-to-end essential system architecture solution is developed for a future billing methodology.

As a development of the Pragmatic Option 1 it could be possible to identify areas of an LDZ that have a single source of supply (from an NTS offtake, or IP PRS etc) where all downstream consumers receive gas from that single point. If a new CV measurement device (and flow measurement if required) was to be installed at that point, all downstream consumers could be billed on the CV of gas delivered through that facility rather than the overall LDZ FWACV as now. This would identify parts of the LDZ network that could be created as separate Charging Areas. To facilitate this, it is recommended that the Gas (Calculation of Thermal Energy) Regulations be reviewed to better understand the potential for the use of within-network CV measurement.

In assessing the feasibility of Composite Option 2, at this stage there is no recommendation that Charging Areas be developed around each offtake from the NTS. Some Offtakes could be suitable (i.e., feeding a single pipeline as described above) but the majority feed into LTS networks where there is dynamic interaction with other offtakes i.e., changes in offtake flow for network management and operational reasons rather than just demand, use of the system for linepack etc. Further network specific understanding and complex modelling work would be required to evaluate and assess Charging Areas development.

In assessing the feasibility of Option 3 Ideal reference should be made to the key findings from the MS11 Smart Metering Laboratory Trials Report. There are a number of technical challenges/limitations including, though not limited to, meter battery life, data reading traffic load and metering specifications for kWh retrieval, requiring further exploration and understanding. Potentially this option may not be workable within the timeframe given the requirement to also consider the implications of a future move to Hydrogen, which would involve the roll-out of hydrogen-specific meters.

For both Option 2 Composite and Option 3 Ideal, the installation of large numbers of CV measurement devices within GB gas networks would be required and this is not a sustainable solution due to the factors identified in Table 1, namely overall cost and emissions from venting.

No advances in technology to overcomes these factors have been forthcoming during the project timeframe. Advances in gas analytics technology are being trialled as part of the separate HyDeploy2 project and other similar products may exist elsewhere. It is recommended that submissions be actively sought for the development of CV measurement devices which are sufficiently accurate, compact, environmentally sustainable and energy-efficient. These could bring significant benefits to the gas industry's transition to net zero.

In assessing the feasibility of Option 4 Modelled CV consideration should include, but not be limited to the following (not listed in any order of significance):

- A review, and potential update, of the Gas (Calculation of Thermal Energy) Regulations to determine whether they could accommodate the use of a modelled CV for billing purposes.
- The application and benefits of online LTS modelling to inform CV at LTS offtakes into the pressure-controlled tiers of the LDZ pipeline system.
- Potential for and benefits of integration of downstream network models for IP, MP and LP systems.
- Identify all critical data items and feeds into the network modelling process and assessing opportunities to streamline data feed processes and maintain data integrity.
- Determining the appropriate frequency, timing and potential for automation of network modelling processes to achieve the correct balance between accuracy and practicality of process, to remain within existing limits on cross-subsidy between consumers.

Additional considerations

The output from the Real Time Network demand modelling project has provided SGN and the industry with an improved understanding of demands in line with the latest appliances and consumer behaviour. If this learning were to be implemented by the industry, this would impact on all current and future network analysis activities. This updated understanding of demands could improve the modelling results undertaken for any of the FBM options as all rely on network modelling.

With the proposed use of network models for consumer billing (either for the allocation of a SMP to a Charging Area or the generation of a modelled CV), the appropriate modelling of consumer demand is key. In addition to the learning from the RTN project, it is understood there is more detailed gas demand data which if readily available to the DNs, would support the use of modelling for billing purposes. It is recommended that this is explored through the industry consultation.

Along with the Xoserve system architecture changes, the requirements for the following should be considered:

- creation of the appropriate interface with Xoserve systems;
- development of the necessary changes to UK-Link billing processes;
- establishing and maintaining critical System User requirements for billing.

It is also recommended that the industry consultation invites and gathers industry feedback to identify aspects or concerns that may not have been considered in this study.

Following industry consultation, it is recommended the Charging Area process that is taken forward is documented as an industry procedure to be followed to ensure consistency of approach for all consumers.

Post implementation, it is recommended that temporary CV measurements are taken at points in the network to verify the Charging Area values to help maintain levels of customer protection.

2 FBM PROJECT OVERVIEW AND REPORT STRUCTURE

2.1 Scope of FBM Project

In summary, the Future Billing Methodology Project explores options for a fair and equitable billing methodology for the gas industry which will be fit-for-purpose in a lower-carbon future. It aims to integrate diverse gas sources without needing to standardise energy content and will inform the industry on billing options for a sustainable gas future.

New and different sources of GS(M)R compliant gas are currently constrained from entering the gas supply network because of the commercial and operational arrangements of the Flow Weighted Average Calorific Value (FWACV) billing methodology currently operated by the industry.

The FBM Project explores options for assigning CV at a more specific level, to avoid the need for additional gas processing to standardise CV within the LDZ and could provide a more robust attribution of gas energy to customers generally for decades to come. With the UK's commitment to reduce green-house gases to "net-zero" emissions by 2050, there is an increased focus on a decarbonised pathway including the use of hydrogen, low carbon and renewable gases in the energy mix, which this Project is a key step along the pathway.

2.1.1 Current Flow Weighted Average CV Explanation

To provide a level of understanding for this report, the following paragraphs provide a summary of the current FWACV mechanism.

The gas meters presently used in the UK measure gas by volume only (except for very large loads which have site-specific CV measurement at the meter) and so the energy content or CV of the gas must be assigned separately for billing purposes. In any Local Distribution Zone (LDZ) there may be a number of different gas sources, each having a different energy content. To meet the same gas energy requirement, a consumer receiving gas from a higher-CV source will require a smaller volume of gas than an equivalent consumer who receives lower-CV gas.

Each LDZ now has several entry points with gases from different sources and with different energy content. The FWACV is calculated from the flows and the CVs of all the gas entering the LDZ. As a consumer protection measure, the FWACV used for consumer billing cannot be more than 1 MJ/m3 above the lowest CV entering the Charging Area – this is known as the CV cap.

Gas supplies connected directly to the Gas Distribution Network are known as "embedded" entry connections; gas transporters currently impose a minimum daily average CV on embedded entry connections to prevent the 1 MJ/m3 CV cap being imposed. A very small volume of low CV gas can cap an entire LDZ. To prevent this, propane is added to enrich low CV gas to meet the target CV; adding carbon to unconventional low-carbon gases is counter-productive.

The CV of the gas received by consumers is dependent on the range of the CVs and flows delivered to the LDZ at the various gas entry points and the consumers' location relative to those entry points. Consumers close to a high CV entry point are likely to receive high CV gas and meter a lower volume of gas for a fixed energy requirement leading to lower bills and vice versa. However, consumers are not billed on the CV delivered to their property but rather on the FWACV of the LDZ.

Under the present arrangements where low CV embedded gas sources are enriched with propane, the variation in consumers' bills within an LDZ can be around £20 per year for the same energy requirement[5], due to the difference in metered volumes between consumers fed by different gas sources. However, if propane enrichment were stopped and the CV cap invoked as a result, the variation in bills could more than double.

[5] Gas Energy Measurement in Consumer Billing report DLC/0059 https://www.ofgem.gov.uk/sites/default/files/docs/2014/08/dlc_report_final_-_gas_energy_measurement_1.pdf

The LDZ FWACV methodology has worked well since 1997[6] and is effective in cost/benefit terms utilising existing entry CV measurements, CV management on the NTS and a CV cap to ensure consumers receive gas with an energy content close to the FWACV. Use of this methodology has limited the difference between consumer used energy and billed energy to a small (and accepted) level. However, to unlock the transition to lower-carbon gases including hydrogen blends and gain their full low-carbon benefit, it will be essential to stop adding propane to these gases. To do this we must be able to assign the energy content of the gas from specific input points at a more local level than under the present LDZ FWACV approach.

2.2 Overall Project Aims and Objectives

The methodology proposed for the overall project was to explore three options for reforming the billing methodology is shown in Figure 8. This report covers the analysis and application of the data from the FBM Project field trials. This validation demonstrates that the network model can, with the appropriate input parameters, replicate the travel and mixing of the measured oxygen over the range of demand conditions and can therefore be used to reliably predict how the network will deliver different gases at varying demand level. Using network analysis tools to model CV, enables a consumer billing impact analysis to determine for example, an embedded Charging Area designed to minimise billing disparities.

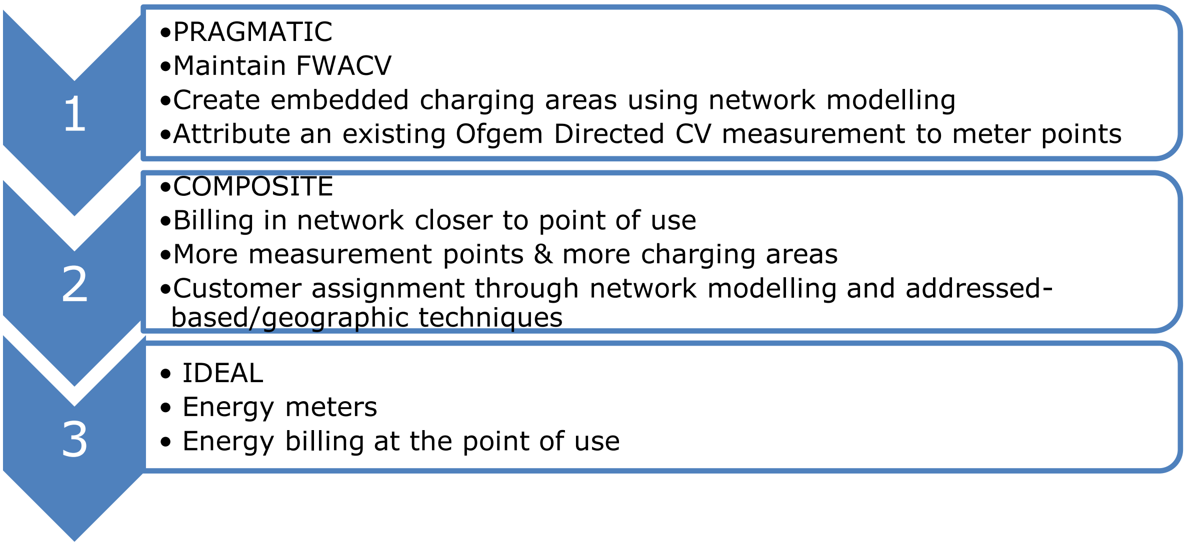

Figure 8 – Three Options Considered for Reforming the Billing Methodology

These three options were proposed with the intention that the overall project recommended solution will be based on one of these. The underlying principle would be that every Supply Meter Point (SMP) would be assigned to an entry point CVDD or the flow weighted average of a group of entry points, taking into account the variations in consumer demand and general/planned network operation over a year. These three options are explained below:

1. Pragmatic - CV measurement at entry only

Network modelling would be used to identify the zone of influence variation around embedded entry points of gas with a significantly different CV. Consumers that are deemed to be within the zone affected by the different gas quality would be allocated to a separate Charging Area with bills based on the local, rather than the LDZ, CV. The key assessment of this option is the determination of a fixed zone boundary for billing purposes. All consumer bills would be based on

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[6] The FWACV mechanism was included in the 1997 amendment of Gas (Calculation of Thermal Energy) Regulations 1996 and Amendment 1997

existing Ofgem Directed CV measurement sites at the NTS offtakes (for the FWACV area), or the Directed CV measurement point of the embedded connection (for the embedded Charging Area).

2. Composite – CV measurement at entry and within network

Network modelling would be used to identify Charging Areas around CV measurement points, whether they be newly installed CV measurement points in the networks (for CV charging purposes) or existing Ofgem Directed CV measurement points (at NTS offtakes and measurement point of embedded connections). There would be a greater number of smaller Charging Areas and the CV assigned to a consumer would be based on the locally measured CV, or a more local FWACV.

3. Ideal – CV measurement local to the meter

Part of the overall FBM project explored whether a measured CV local to the consumer could be transmitted to a smart meter and that the consumer could therefore be billed on current gas energy use rather than the measured volume of gas at a fixed predetermined CV. This has been covered in the MS11 Smart Metering Laboratory Trials Report.

Through the data collection and project execution, these three concepts have remained valid and form the basis of this report.

2.3 Report Structure

This report has been structured to show how the project conclusions and recommendations have been developed in line with the Network Innovation Competition network modelling objectives:

- Review the measured oxygen, flow and pressure data gathered through the field trials
- Use the measured oxygen data in the network model to show that the zone of influence of an embedded entry gas can be modelled
- Simulate the penetration of the embedded entry gas through the network by CV zone modelling. This will provide an assessment of the CV delivered to individual consumers across the network, taking the network operational characteristics into account
- Propose a method to define local Charging Areas for gases entering the network with different CVs to the existing FWACV
- Document a high-level procedure to enable the allocation of a consumer to an entry point that more closely reflects the actual energy content of gas received by that consumer
- Try to improve the difference between used and billed energy; recognising there are cross-subsidies that are intrinsic to the averaging in the FWACV approach.

The report sections are summarised below:

- **Section 3** covers the setting up of the field trial with the sensor locations and the reasons for the use of oxygen measurements rather than direct CV measurement. The determination of the oxygen sensor locations is described, and information provided on the time period over which data was collected.

- **Section 4** provides an insight into the data collected from the Chittering and Hibaldstow networks showing a visualisation of the variation in oxygen values at each sensor and the penetration of the biomethane into the network across the data gathering period.

- **Section 5** describes the network models applicable to the two networks and how these were set up to replicate as far as possible the network setup and operating conditions over the data modelling period.

- **Section 6** builds on the data visualisation work in Section 4 and provides the evidence to show that consumers do receive gas from different entry points into the network at different demand levels. The network analysis models were used to predict a biomethane-affected zone comparable to that experienced and that the models could be used as a basis for defining a suitable Charging Area.

  This section demonstrates from the measured oxygen data that gas from the biomethane sites travels through the Cambridge and Lincolnshire networks and the distance travelled is linked to the level of network demand, biomethane flows and network dynamics. This is in line with expectations given that the biomethane plant delivers gas at a relatively constant flow rate into the network and as the network demand reduces, the gas must travel further to be used by consumers.

- **Section 7** having demonstrated that the network models used by DNs can reliably predict the penetration of gas into the network, the report demonstrates that it is possible to utilise the functionality of the network analysis software to show how the CV of gas varies in a network at various demand levels.

  The network analysis models can be used to model gases with sources of differing CVs. In addition, it has been possible to draw firm comparisons between the natural zone of biomethane from Chittering and the low CV area predicted by the network analysis model. These comparisons provide the evidence that the example network models would also be suitable for the definition of a CV Charging Area.

- **Section 8** sets out at a high-level, four possible methods for identifying Charging Areas for further exploration including industry consultation, to begin unlocking the decarbonisation of GB's existing gas networks and maintaining an equitable billing outcome for consumers. Fundamental to each option is that all SMPs are allocated an individual billing CV. SMPs may be grouped together and assigned to the same CVDD or modelled CV, but there is an underlying assumption that billing CVs are assigned at SMP level.

  Currently the Charging Area is an LDZ, a geographically defined area with identifiable entry points for gas, each of which has fiscal flow measurement and an associated gas quality measurement device.

  The concept behind both the Pragmatic and Composite Options is to have distinct Charging Areas for embedded entry points with gases of a CV different to the prevailing CV. The possible methods for defining Charging Area start with this concept and develop to address more complex scenarios.

- **Section 9** sets out the factors that will need to be considered when determining a future billing methodology. The following areas are highlighted:

  - Network model and parameters - basis for network modelling.
  - Identification of consumers within a defined Charging Area for uplift to Xoserve systems etc
  - Management of a Charging Area
  - The cost/benefit of additional CV sensors
  - CV Shrinkage issues
  - Xoserve, Shippers and billing systems impact
  - Impact on required entry capacity due to removal of need for propanation/ballasting
  - Addressing areas with several embedded entry points of differing entry CVs
  - Operational issues and impact of the billing CV used.

- **Section 10** sets out the Conclusions and Recommendations from the network modelling evaluation and highlights areas where additional investigation might be warranted.

3 FIELD TRIALS

3.1 Introduction

Field trials were planned to provide essential learning about the zones of influence exerted by embedded LDZ input points, together with the range and strength of factors that affect those zones under varied system conditions throughout the year.

Cadent proposed the locations of two field trials around embedded unconventional gas injection points within the Cadent network:

1. The Low Pressure (LP) network centred on the Medium Pressure (MP) feed from Chittering biomethane input; this is referred to as the Cambridge network (in East Anglia) throughout this project report.

Figure 9 – Location of Chittering Biomethane Plant

2. The geographically more extensive MP network centred on Hibaldstow biomethane input. This trial also looked at the impact with the upstream Intermediate Pressure (IP) system and the potential dispersion into the downstream LP network; this is referred to as the Lincolnshire network (in East Midlands) throughout this project report.

Figure 10 – Location of Hibaldstow Biomethane Plant

These two trial networks were selected as representative of the development of biomethane connections in terms of operation, pressure tier connection and contracted flow rates. They feed into networks that have other gas entry points so the mixing of gases from different sources could be investigated and modelled. The networks that they feed are reflective of general UK demands and customer behaviour. These chosen trial sites are typical of embedded entry points and it is anticipated that the learning can be applied elsewhere.

The field trial measurements were required to validate the network modelling technique as a robust and equitable methodology for the creation of Charging Areas and the allocation of CV. These measurements were used for Option 1 Pragmatic and Option 2 Composite but not in Option 3 Ideal which considers measured CV local to the consumer and transmitting it to a smart meter.

3.2 Sensor Data

At the NIC Bid proposal stage tracing options were considered. Tracing by CV difference would have been impractical as any biomethane injected into the network is already propane-enriched, so the difference in CV between this and natural gas from NTS sources will be minimal. Propane enrichment could not be suspended for the purpose of this study as this would automatically trigger CV capping and would create significant impacts on consumer billing and transfer excluded gas energy costs into the NTS shrinkage account. Therefore, the field trials focussed on tracking the biomethane using a unique marker, that of oxygen concentration, as oxygen concentration is typically an order of magnitude higher in biomethane than natural gas.

In addition to oxygen measurements, indicative gas flow was measured along with the CV at selected sites.

For further detail on the sensor and measurement equipment see report 114D803D-62 MS12 Final Report on Field Trial Progress, December 2020.

3.2.1 Oxygen Sensor Data and Settings

Oxygen sensors have been installed in both networks, Cambridge and Lincolnshire. Oxygen content has been used as a marker for the presence of biomethane because its concentration is typically an order of magnitude higher in biomethane than natural gas. NTS gas can contain up to 0.001 mol% oxygen (<10 ppm) and biomethane contains <1 mol% oxygen (<10,000 ppm)[7]. The operating range for the measurement of oxygen concentration was chosen as 0-200 ppm to measure accurately the lower readings and therefore understand how far into the network the biomethane reached.

Setting sensors to measure a wider range would not have supported the project, as the lower resolution would have not provided the required confidence to discriminate between gas originating from the NTS and biomethane at its furthest extent of penetration across the network. At wider range settings the sensitivity to small changes is reduced and the measurements can become unstable.

To measure accurately from 0 to 0.2 mol% would have required a sequential bank of oxygen sensors, each calibrated on a separate concentration range, which would not be technically or physically feasible in the available network locations. Since the aim of the project was to track the penetration of biomethane and to model molecular oxygen concentration and calorific value, a single sensor setting was deployed.

The sensor recordings have provided a dataset of oxygen values which can be interpreted as follows:

- Sensor response <10 ppm indicates NTS gas
- Sensor response between 10 and 200 ppm indicates a blend of NTS gas and Biomethane; the nearer to 10 ppm the lower the biomethane concentration

[7] See Section 4.1 of 114D803D-62 MS12 Final Report on Field Trial Progress, December 2020 for further detail on the parameters of the oxygen sensors.

- Sensor response of 200 ppm (upper limit of sensor) indicates there is a blend of NTS gas and Biomethane, or 100% biomethane; i.e., oxygen at a concentration of >= 0.02 mol%[8].

In addition to oxygen levels, the sensors recorded system pressures; regulator inlet and outlet pressures and gas flow, and street location network pressures.

3.2.2 Indicative Regulator Flow Data

An innovative and low-cost gas flow measurement technique was developed by Advantica (now part of DNV GL) in 2002 and has been trialled on regulator stations as part of the FBM project. The inlet pressure, outlet pressure and governor regulator position (percentage of open/closed) was used to estimate the gas flow. This data has been used to help to model the downstream demand and validate the flow dynamics across the networks. It was not possible to install this equipment on all the regulators as certain types of regulator had not been included in the 2002 work.

3.2.3 Gas PT

GasPT (Gas Properties Transmitter[9]) is a device that determines the physical properties of natural gas. Using GasPTs, CV was measured at four selected sites, two in each area, primarily to demonstrate the transmission of measured CV data to smart meters, primarily to support the Ideal Option. This data has been used in CV modelling section as an input value for the CV of the NTS gas see Section 7.

3.3 Sensor Installation

3.3.1 Proposed Locations

Assuming a constant flow rate from the embedded entry, the area affected by the embedded entry gas varies with the network demand. Depending upon the operation of the network, this area will increase during periods of lower demand (daily and seasonal).

Network modelling was initially used to determine the location of the field trial measurement points to capture fluctuations in the embedded input point's zone of influence across the range of demand conditions. In the case of a typical biomethane injection point, which has a fairly constant supply rate into the network, the zone of influence it exerts generally widens across the local network as demand levels reduce and vice versa. This is shown in Figure 11 and Figure 12.

[8] A value of 200 ppm indicates a ratio of NTS to Biomethane of 9:1, assuming NTS at 10 ppm and Biomethane at 2000 ppm.
[9] It is also an approved device for measuring CV under Ofgem Direction at biomethane network entry points.

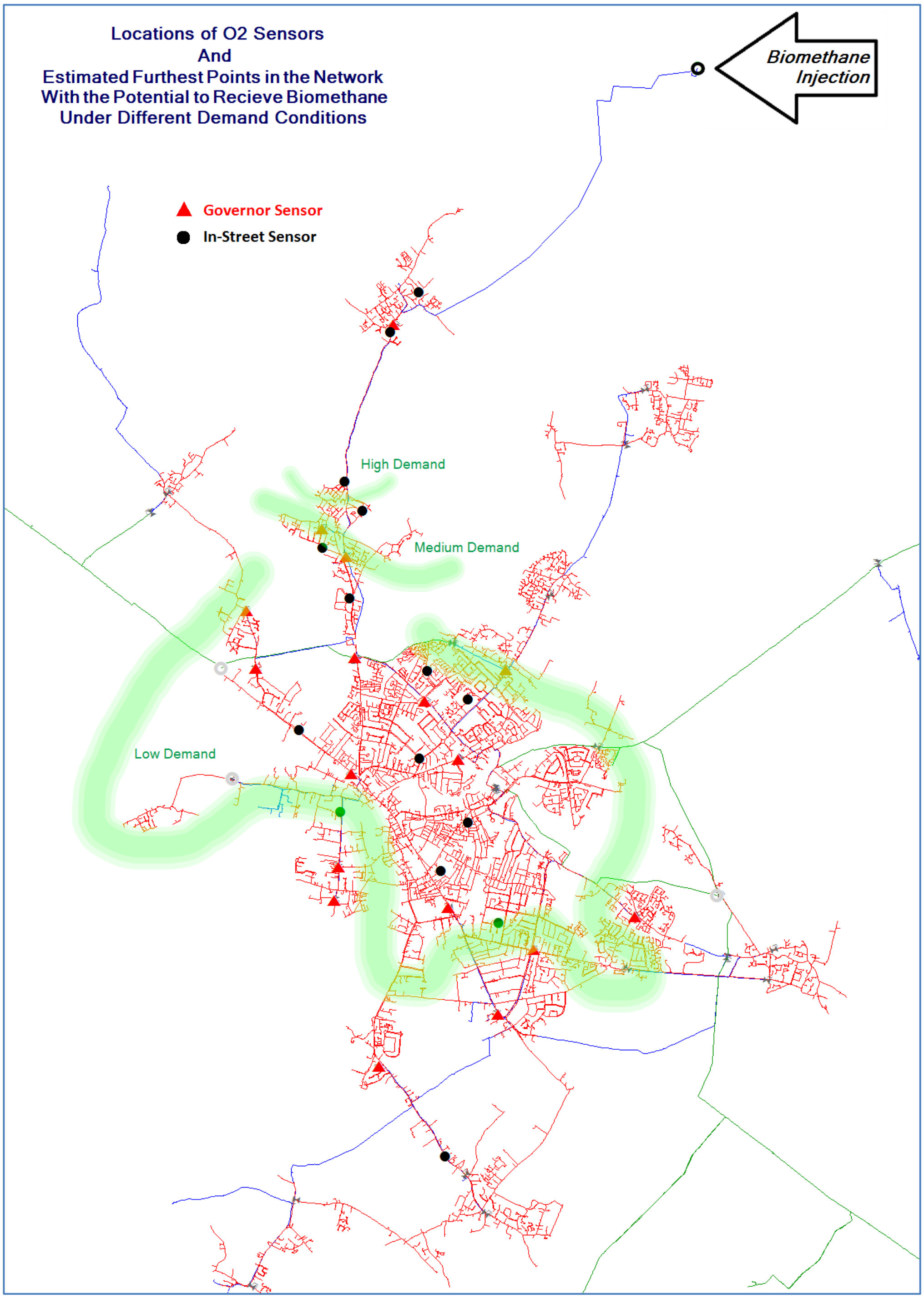

Figure 11 – Cambridge Network Modelled Zones for Field Trial Sensor Location Plan

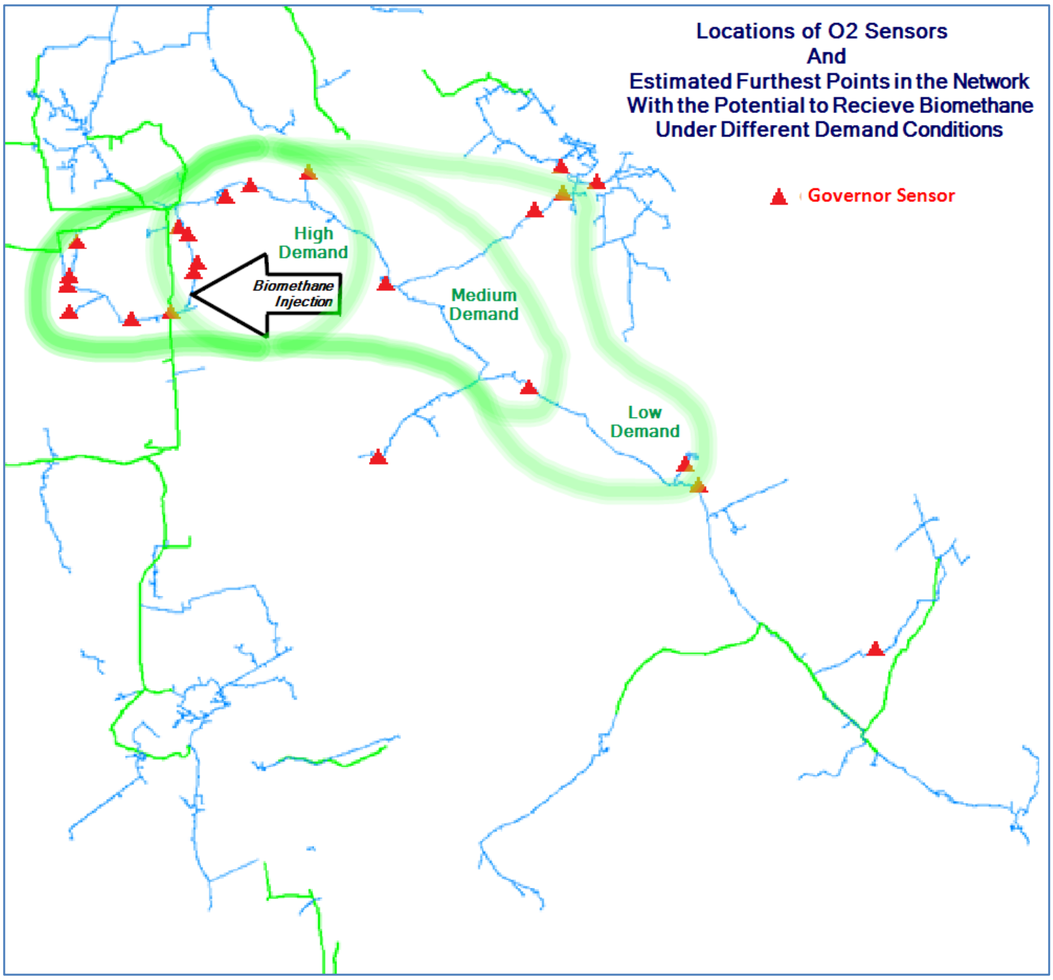

Figure 12 – Lincolnshire Network Modelled Zones for Field Trial Sensor Location Plan.

3.3.2 Final Installed Locations

Over the duration of the sensor measurement planning and installation phase there were a number of site-specific issues that resulted in fewer sensors being installed than initially planned for[10]. The following images provide an overview of the final installed sensor locations and a full list is provided in Appendix B.

[10] For further detail on the installation of the sensors see report 114D803D-62 MS12 Final Report on Field Trial Progress, December 2020

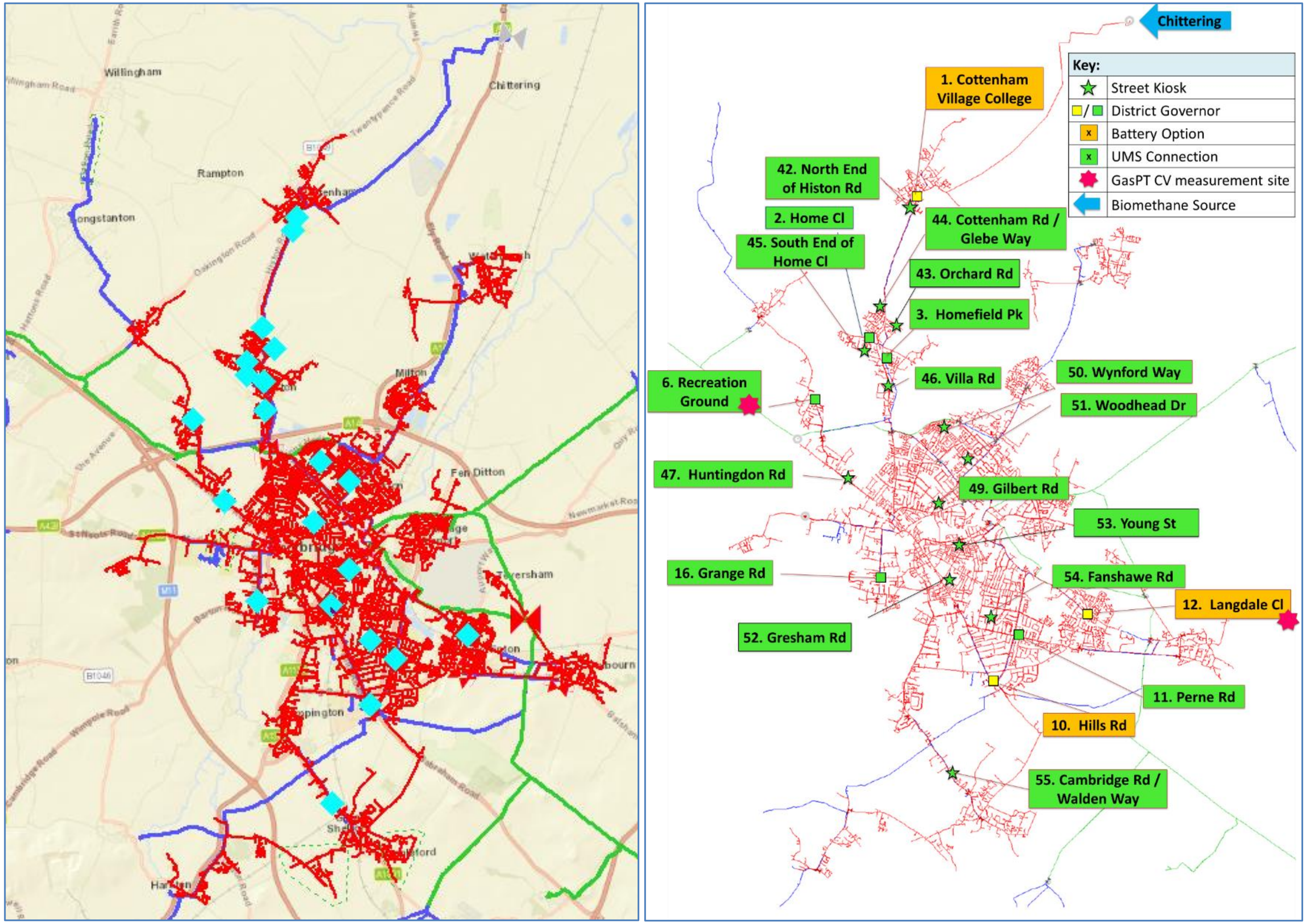

Figure 13 – Locations of the Final 21 Sensors in the Cambridge Network

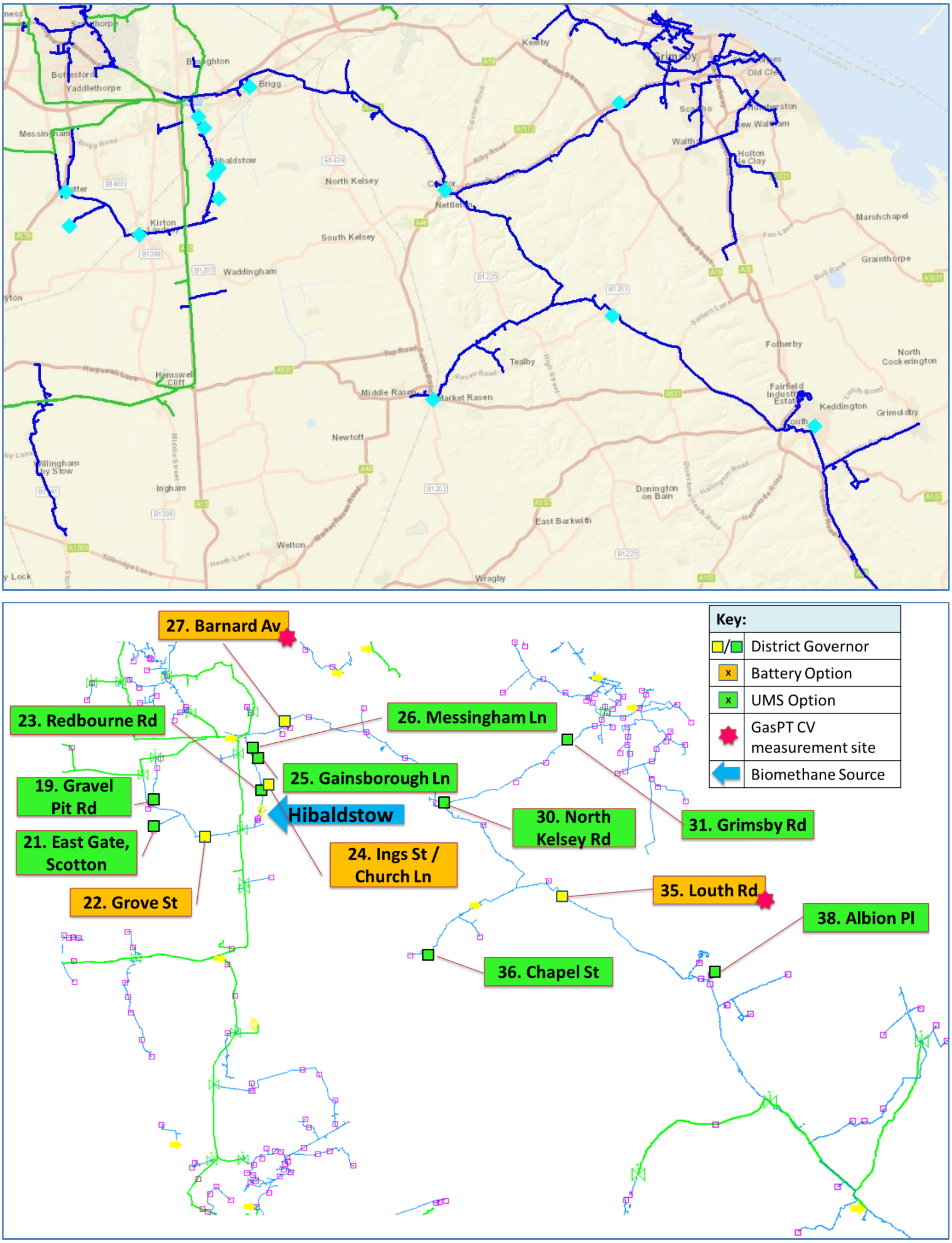

Figure 14 – Locations of the Final 13 Sensors in the Lincolnshire Network

3.4 Data Collection Period

Due to the range of technical and site-specific issues and the impact of the Covid-19 pandemic described in MS12 Final Report on Field Trial Progress the data set has been limited in relation to the original ambition.

Whilst the observation of peak and minimum demand conditions cannot be guaranteed within any set time frame, the key aim is to demonstrate that the network model can reflect the behaviour of the physical network across a range of demand conditions and can therefore be used to determine how the network will perform at any demand level, including peak day.

The following sections and tables show the breakdown of the data gathering, with the green cells identifying a full complement of data being recorded and the orange cells identifying periods of partial data.

The contracted data gathering period ended in October 2020 any data collected from this point onwards was provided under a best endeavours basis and may not be a comprehensive set.

3.4.1 Cambridge Within Street Sensors

The phasing of the street installations and transmitting of data commenced with site FBM44 on 9th December 2019 and FBM49 being the last to start transmitting data on 3rd June 2020.

FBM Site ID	Oct-19	Nov-19	Dec-19	Jan-20	Feb-20	Mar-20	Apr-20	May-20	Jun-20	Jul-20	Aug-20	Sep-20	Oct-20	Nov-20	Dec-20	Jan-21
42				27-Jan												
43				21-Jan												
44			09-Dec													
45			11-Dec													
46			11-Dec													
47			18-Dec													
49									03-Jun							
50				06-Jan												
51			18-Dec													
52			18-Dec													
53			18-Dec													
54				21-Jan												
55			18-Dec													

Table 2 – Cambridge Within Street Sensors Installation and Data Availability (green cells = full complement of data, orange cells = partial data)

3.4.2 Cambridge Regulator Sensors

The phasing of the regulator installations and transmitting of data commenced with FBM11 transmitting data from 14th October 2019 and an estimated flow data set from 12th February. The last site to start transmitting data was FBM6 in October 2020.

FBM Site ID	Oct-19	Nov-19	Dec-19	Jan-20	Feb-20	Mar-20	Apr-20	May-20	Jun-20	Jul-20	Aug-20	Sep-20	Oct-20	Nov-20	Dec-20	Jan-21
1											04-Aug					
2					13-Feb											
3												25-Sep				
6													23-Oct			
10											06-Aug					
11	14-Oct															
12											06-Aug					
16											04-Aug					

Table 3 – Cambridge Regulator Sensors Installation and Data Availability (green cells = full complement of data, orange cells = partial data)

For Cambridge, while the oxygen data gathering for the majority of the street sites has been in place since December 2019, a concurrent set of data with most of the regulator sites becomes available from August 2020.

3.4.3 Lincolnshire Regulator Sensors

The phasing of the regulator installations and transmitting of data commenced with FBM23 transmitting data from 11th February 2020. The last sites to start transmitting data were FBM22 and FBM27 in September 2020.

FBM Site ID	Oct-19	Nov-19	Dec-19	Jan-20	Feb-20	Mar-20	Apr-20	May-20	Jun-20	Jul-20	Aug-20	Sep-20	Oct-20	Nov-20	Dec-20	Jan-21
19										06-Jul						
21										07-Jul						
22												15-Sep				
23					11-Feb											
24												14-Sep				
25						11-Mar										
26						11-Mar										
27												15-Sep				
30												14-Sep				
31									04-Jun							
35												14-Sep				
36										02-Jul						
38						04-Mar										

Table 4 – Lincolnshire Regulator Sensors Installation and Data Availability (green cells = full complement of data, orange cells = partial data)

For the Lincolnshire network, a full data set became available in September 2020 so there is a reduced number of sites available for the summer months of low network demand.

4 DATA VISUALISATION

4.1 Oxygen Data

With the oxygen sensors successfully recording oxygen concentration levels within the network this showed a differentiation between the gas from the biomethane site and gas supplied from the NTS via a DN offtake and areas where a mixture of the two gases was supplied. A variation has been seen between the oxygen sensors values at individual sites and across the network.

The variation in measured oxygen concentration levels with overall network demand and location relative to the embedded entry confirms the patterns predicted by that initial modelling (see Section 3.3.1).

4.1.1 Geographic View of Oxygen Data

The oxygen sensor data has been overlaid on a map view of the networks in order to show geographically the penetration of the biomethane gas into the networks.

4.1.1.1 Cambridge

The data from all the sensors was processed and is represented in the following sequence of images with the geographical background. The biomethane entry at Chittering is denoted by the blue marker and all the sensors (street and regulator) that were recording on 23rd June 2020 are denoted by the circular spots. The key to the oxygen concentration level is on the right-hand side of each image; the darker the colour spot, the higher the level of oxygen concentration, with dark green indicating a level of 200 ppm or above and anything less than 10 ppm is shown as pale yellow.

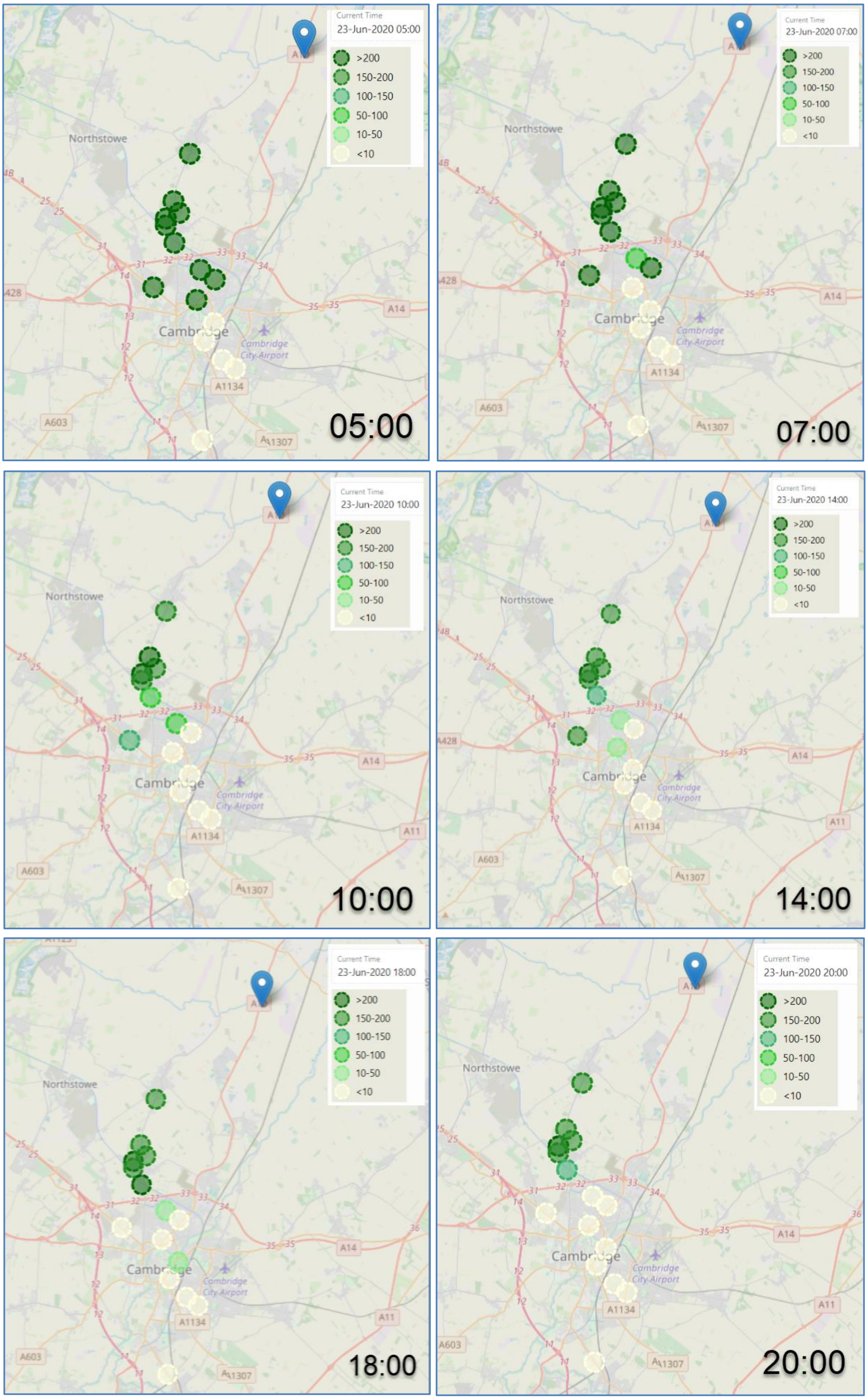

Figure 15 – Sequence of Images Showing the Oxygen Data in Cambridge 23rd June 2020

The images show the sensors successfully recording variations in oxygen concentration levels across the Cambridge gas network.

Looking at the first time slot of 05:00 the sensor locations from the biomethane entry point heading south towards the north of Cambridge city centre are all dark in colour, indicating an oxygen level of >200ppm. The locations further away from the biomethane entry point are all light in colour, indicating an oxygen level of <10ppm.

Comparing the first time slot image with subsequent time slots, there is a reduction in the number of sensors recording oxygen level of >200ppm. In addition, the location of these higher oxygen concentration sensors are closer to the biomethane entry point. This pattern of oxygen recordings shows the zone of influence of the gas from the biomethane entry as it reduces across the local network as demand levels increase.

4.1.1.2 Lincolnshire

The data from all the sensors has been processed and is represented in the following sequence of images in Figure 16. The biomethane entry at Hibaldstow is denoted by the blue marker and all the sensors that were recording on 5th October 2020 are denoted by the circular spots. The key to the oxygen concentration level is on the right-hand side of each image; the darker the colour spot, the higher the level of oxygen, with dark green indicating a level of 200 ppm or above and anything less than 10 ppm is shown as pale yellow.

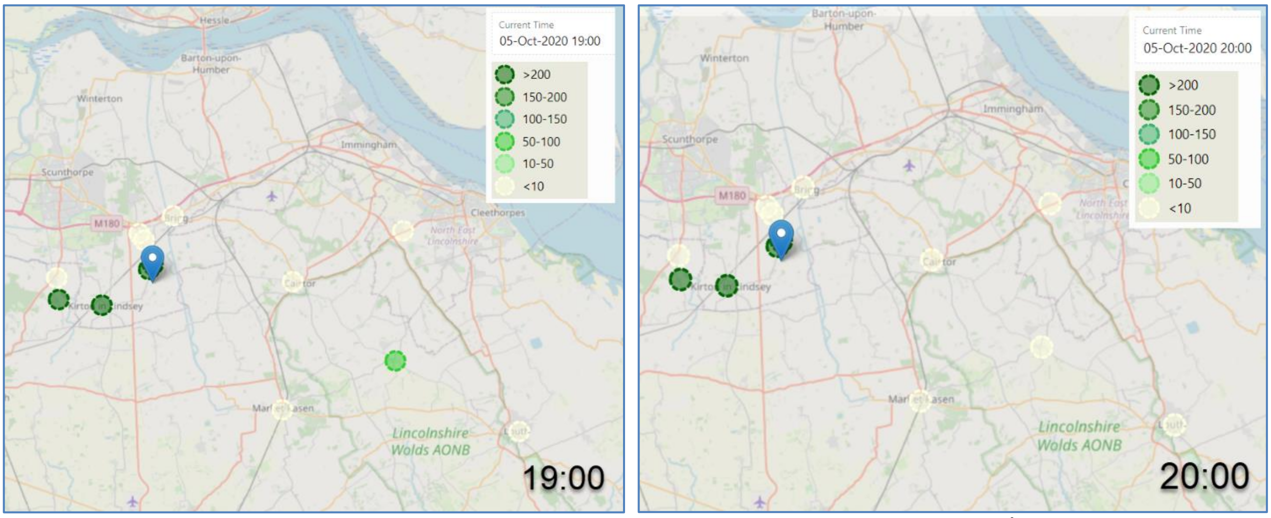

Figure 16 – Sequence of Images Showing the Oxygen Data in Lincolnshire for 5th October 2020

The images show the sensors successfully recording variations in oxygen concentration levels across the Lincolnshire network. The recordings show that across the network there is a difference between the gas from the biomethane site and the gas from the NTS (via DN Offtakes).

As with the data from Cambridge, at periods of higher demand across the day, there are fewer sensors recording a higher concentration of oxygen during periods of higher demand (17:00 onwards) and more sensors recording higher oxygen levels during lower demand periods of the day (15:00).

4.1.2 'Stacked' View of Oxygen Data

To further interrogate the data and provide a view of the spread of the biomethane gas over a longer time frame and the frequency with which this gas was seen across the network, the data has been presented in a 'stacked' view. This gives a concurrent view of each of the oxygen measurements (up to the upper limit of 200ppm) at the sensor locations.

In the subsequent figures, the average daily oxygen measurements at each sensor location have been stacked on top of each other for a particular time period. The individual sensor locations are shown as a colour block and are presented, from the bottom to the top of the chart, in distance from the biomethane entry point; the x-axis on the left-hand side is the sum of the individual oxygen measurements. In addition, the data also has the biomethane entry volume of flow, with the relevant axis [(Chittring Flow (Daily Sum)] on the right-hand side.

When the coloured blocks are greater in number and / or taller in size and contributing to a greater overall stack height, this demonstrates that the biomethane has travelled further into the network. When the coloured blocks are fewer in number and / or smaller in size contributing to a lower overall stack height, this demonstrates that the biomethane has been consumed closer to the embedded entry point.

Where there is an individual coloured block smaller in height than the 200 block, this represents an oxygen reading of less than 200 ppm at that location indicating the sensor is recording gas that is definitely a blend of biomethane and NTS gas, for example FBM47.

Note:

1. Reference should be made to the tables in Section 3.4 because if a sensor is not reading it will not appear in the stacked view and could be mis-interpreted as a 'zero' ppm read.
2. The Y axis refers to the sum of the ppm of all the sensors that are recording. As the number of sensors changes, as does the scale of the axis; comparing the height of two graphs without reference to the Y axis scale could be misleading.

4.1.2.1 Cambridge

With reference to Section 4.1.2 above, in Figure 17, with a time on the X axis between 01-01-2020 and 31-01-2021, it can be seen that the average daily biomethane flow (red line with right-hand Y axis) is around 30 kscmd (thousands of standard cubic meters per day day). With the exception of FBM42 (once the sensor starts recording in later January 2020), the average daily oxygen measurement at each of the sensor locations varies i.e., the column height for each block of colour is not a constant height of 200ppm against the left hand Y axis.

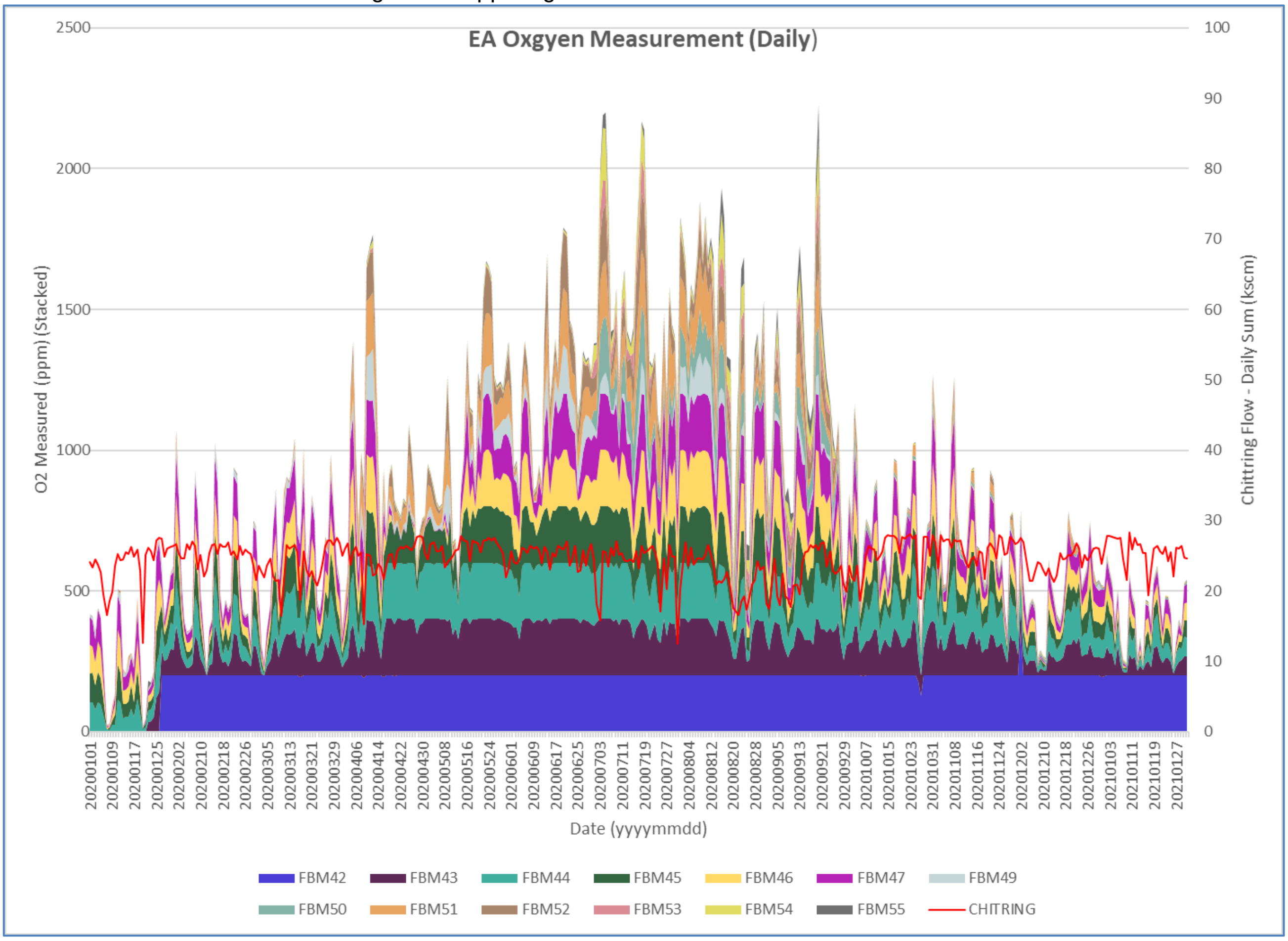

Figure 17 – Stacked View of Cambridge Within Street Sensor Oxygen Recordings

From the data in Figure 17, it can be seen that during the summer months (the middle section of the chart) the cumulative stack height is larger compared to the winter months. The stack heights of individual sensors in the winter months are lower compared to the summer months. As the biomethane is absorbed closer to the point of entry, there are fewer sensors receiving oxygen and a reduced concentration of oxygen where it is measured. This shows the penetration of biomethane into the network is reduced during periods of higher demand.

With reference to Section 4.1.2 above, in Figure 18, shows the stacked view of the oxygen readings for the Cambridge regulators from 01-08-2020 to 31-01-2021 (X axis).

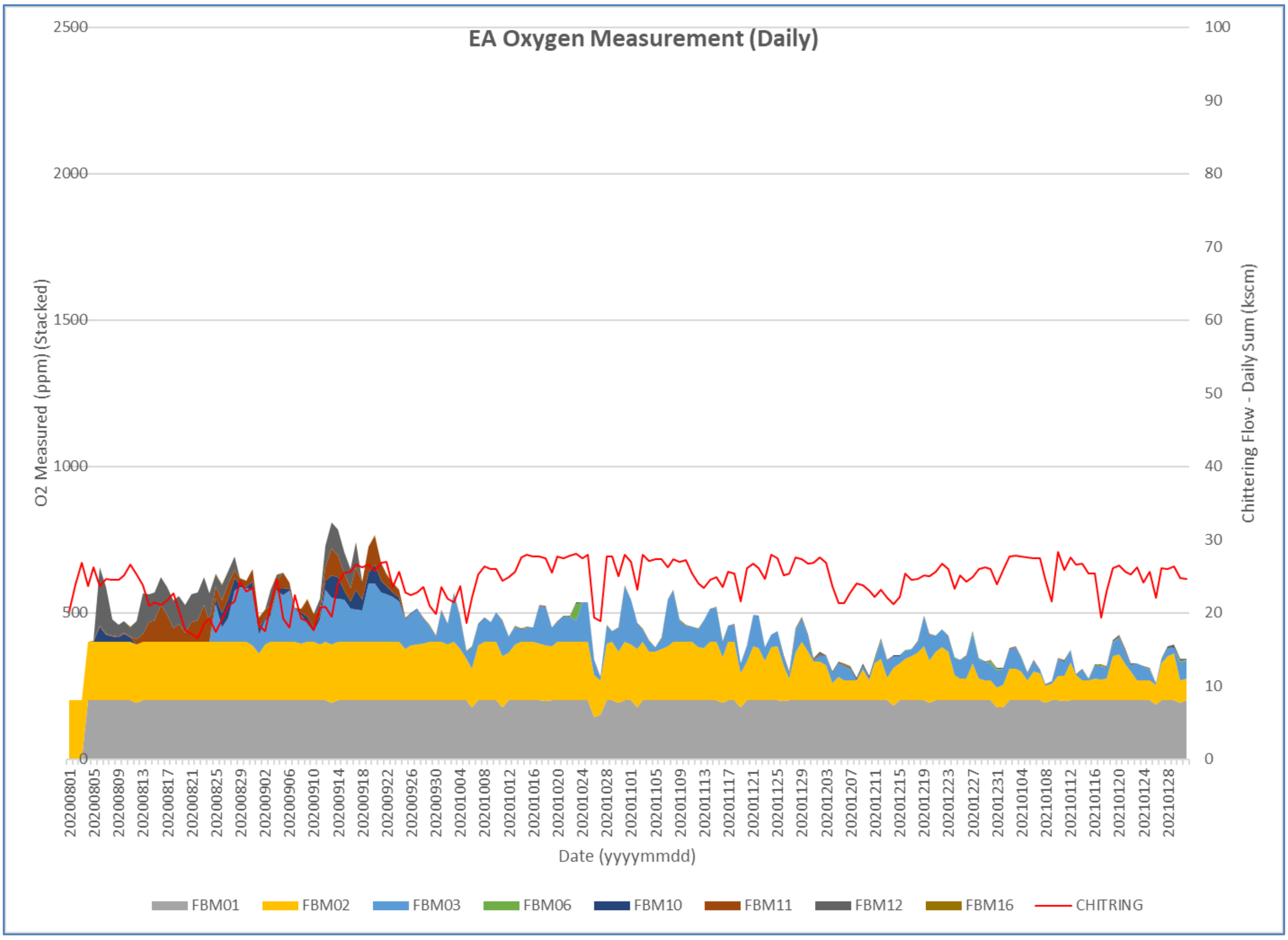

Figure 18 – Stacked View of Cambridge Regulator Sensor Oxygen Recordings

There are fewer months-worth of data as the data presented here covers the period when the majority of sensors were recording. As some of the regulator sensors stopped transmitting data, caution should be applied when interpreting the spread of the biomethane from the oxygen recordings. However, the transmission of data from FBM01, FBM02 and FBM03 remained constant and the column height for FBM02 and FBM03 began to drop away from September 2020 indicating a reduction in concentration of oxygen levels where it is measured.

4.1.2.2 Lincolnshire

In Figure 19, with a time on the X axis between 01-01-2020 and 31-01-2021, it can be seen that the average daily biomethane flow (purple line with right-hand Y axis) is around 1200 kscm. For the Lincolnshire network, there were three distinct periods when the sensors were installed, March 200, July 2020 and September 2020. As a comprehensive data set only became available in September 2020, a comparison with the data from the proceeding months could be misleading. The data available shows the average daily oxygen measurement at each of the sensor locations varies i.e., the column height for each block of colour is not a constant height of 200 ppm against the left-hand Y axis.

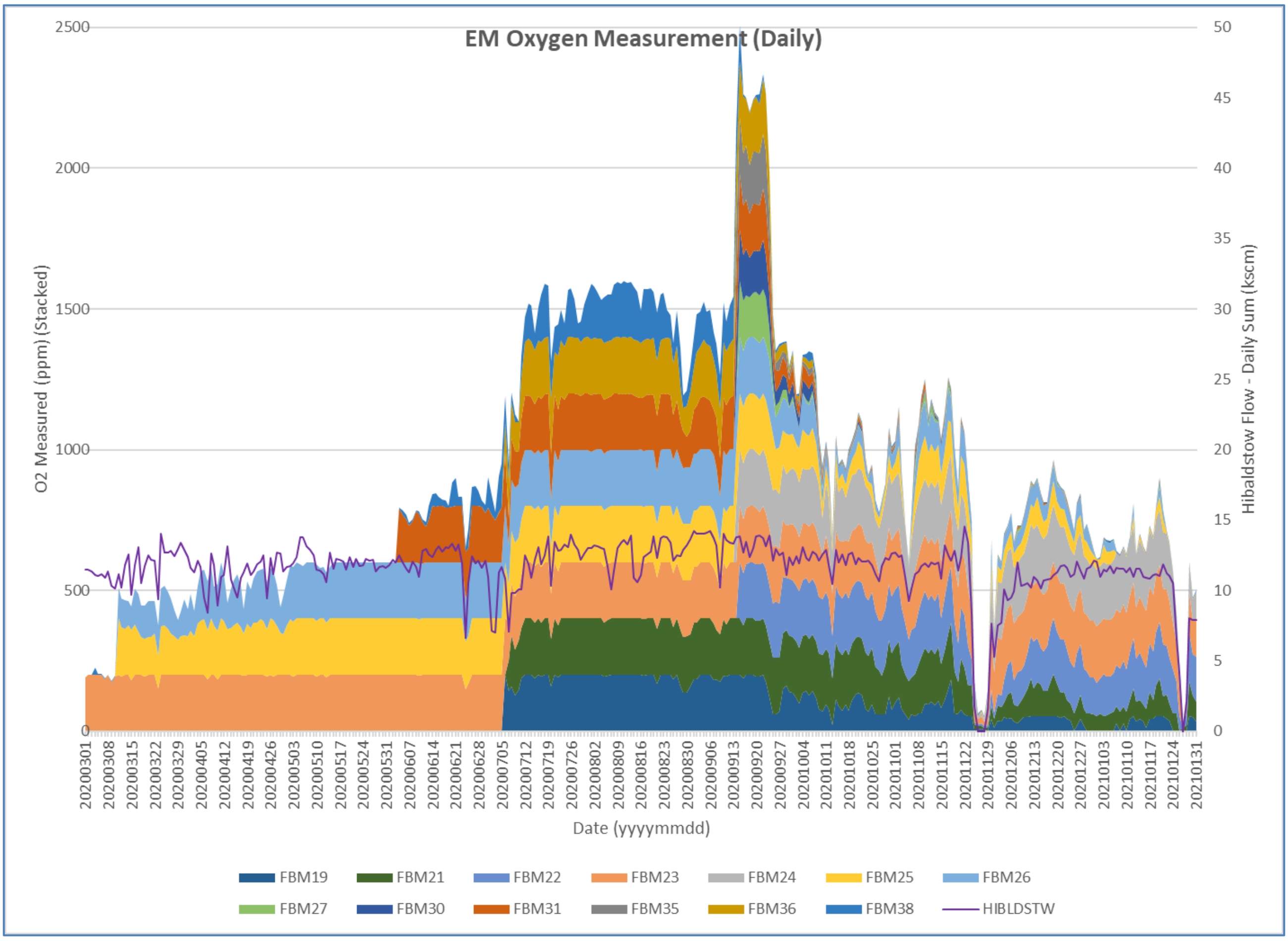

Figure 19 – Stacked view of Lincolnshire Regulator Sensor Oxygen recordings

For the Lincolnshire network, there were three distinct periods when the sensors were installed, during March 2020, July 2020 and September 2020. From the data in Figure 19, it can be seen that from September onwards, when all of the loggers were recording data, there is a short period of time when the cumulative stack height is larger compared to the later months of October and more noticeably November, December and January 2021. The stack heights of individual sensors in the winter months are lower compared to the summer months. As the biomethane is absorbed closer to the point of entry, there are fewer sensors receiving oxygen and a reduced concentration of oxygen where it is measured. This shows the penetration of biomethane into the network is reduced during periods of higher demand.

4.2 Indicative Regulator Flow Data

The flow data estimated through the low-cost gas flow measurement device has provided indicative regulator flows that is not generally available in DN networks. As described in Section 3.2.2, it was not possible to install devices and measure flow at all the regulators in the test sites. Figure 20 shows an example of the data that has been gathered, both sites showing an expected diurnal profile of the downstream demand.

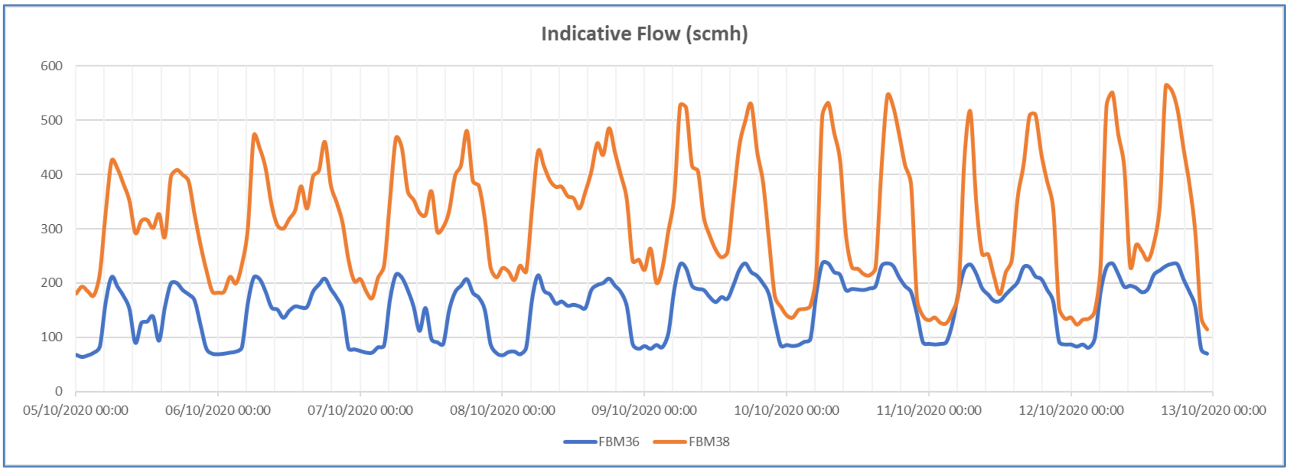

Figure 20 – Example of Indicative Flow Data for 2 Sites in the Lincolnshire Test Area

The flow data gathered was used to validate the relevant modelled regulator flows. In addition, it was used as a comparator for the network demand in the model to align with the demand experienced in the network during the data gathering period.

4.3 Gas PT Data

The CV data that was recorded at the four locations in the test sites was used in the network modelling. Further detail on this is given in Section 7.

5 NETWORK MODELLING

5.1 Overview

Network models are used by all UK DNs to develop the capital plans for system development and replacement as well as managing routine and non-routine operations on the network. These DNs use network modelling to underpin their strategic development plans and operational support. The stated aim of this project is to compare the operational performance of these two test networks (using the oxygen measurements) with the predictions of the relevant network model and if appropriate then develop a straightforward network modelling methodology that can be used by all DNs to determine an appropriate zone around embedded entry points for billing purposes.

5.2 Base Network Analysis Model

Cadent provided DNV Digital Solutions with a copy of their latest network analysis models for the areas related to the two biomethane test sites. Using the different hydraulic software modelling tools of Synergi Gas (used for an example of transient analysis) and GBNA (used for an example of steady-state analysis), the models were manipulated to simulate selected conditions over the data collection period. Over the data collection period, where there have been changes to both the base demand and pipework configuration, this data was made available to update the network analysis models where appropriate.

5.2.1 Demand Scaling

The base network analysis models used by DNOs are typically their highest demand scenario model i.e., simulating the 1 in 20 peak demand. These conditions were not seen during the test data period and as such demand scaling was applied to the peak network demands to simulate not only the annual profile, but also the diurnal profile, of demand.

5.2.2 Pipe Changes

The original site selection process in 2017 used the then current network models. The updated versions of the network analysis models were provided by Cadent for the data gathering period of 2019-20.

5.2.3 FBM Sensor Data

The network modelling has used the data gathered from the FBM Sensors (detailed in Section 3). It has been used in different ways, for example:

- The recorded outlet pressures at the selected MP to LP regulators in the Cambridge network have been used to set the pressure at these regulators on the model.
- The within street measured pressures, have been used to aid the model comparison process.
- Within Synergi Gas, the measured oxygen level has been used as a reference value to compare with modelled oxygen values using tracing functionality.

5.2.4 Cadent Operational Data

Along with the data from the FBM sensors, to help to set up the network analysis models to best represent the conditions being modelled, additional data was provided by Cadent including:

- Outlet pressures for some IP to MP regulators
- Outlet pressures for some MP to LP regulators
- Hourly flow and pressure data for selected sources and regulators
- Biomethane entry flow rates for both Chittering and Hibaldstow

Appendix C contains a table of both the FBM sensor data and the Cadent operational data, where and how it has been used in the network modelling.

6 MODELLING OF THE MEASURED PENETRATION OF OXYGEN IN THE TEST NETWORKS

6.1 Overview

Through the data visualisation (Section 4) the evidence is available to show that consumers do receive gas from different entry points into the network. With the principle of consumers receiving gas from different sources established, it is important to show that the network analysis model can be used to predict a biomethane-affected zone similar to that experienced and that such a model could be used as a basis for defining a suitable Charging Area.

6.2 Modelling of Cambridge Network

For the Cambridge network, detailed comparisons of the oxygen data were undertaken for 4 sets of dates where there is a concurrent set of regulator and street data which show the variation in oxygen levels for differing LDZ demand conditions:

- Sunday 26th – Wednesday 29th July 2020 approximately 14% 1:20 Forecast Peak Day Demand 2020-21 EA LDZ, an example of a low demand summer condition.
- Saturday 26th – Tuesday 29th September 2020 approximately 16% 1:20 Forecast Peak Day Demand 2020-21 EA LDZ, an example of an autumn low demand condition.
- Monday 26th – Thursday 29th October 2020 approximately 36% 1:20 Forecast Peak Day Demand 2020-21 EA LDZ, an example of an autumn mid-demand condition.
- Thursday 7th – Friday 8th January 2021 approximately 79% 1:20 Forecast Peak Day Demand 2020-21 EA LDZ, an example of a high demand condition.

Using the network analysis model set with the measured parameters detailed in Section 5, the Synergi Gas software is able to model gas as it flows through and mixes within the network. In summary, for each of the modelled time periods in the subsequent sections, the following changes were made to the model:

- Network demands were scaled using an annual load profile per demand category tag to reflect a percentage of the daily demand,
- Network demands were further scaled using a daily profile to reflect the diurnal profile,
- Supplies into the network were profiled / set to their measured pressure or measured flow to replicate the conditions experienced,
- Regulators within the network were profiled / set to their measured pressure to replicate the conditions experienced,
- The supply gas of Chittering was set with an oxygen value of that recorded over the assessment period, typically 2000 ppm,
- The supply gas of all other entry points was set with an oxygen values in line with the maximum allowed through the NTS, 10 ppm.

6.2.1 Sunday 26th – Wednesday 29th July 2020

Figure 21 shows the stacked view of the hourly oxygen readings for the period 26th – 29th July 2020. The data shows that over a significant period of the time, many sensors were recording oxygen levels of 200 ppm. This means that the biomethane was penetrating far into the network.

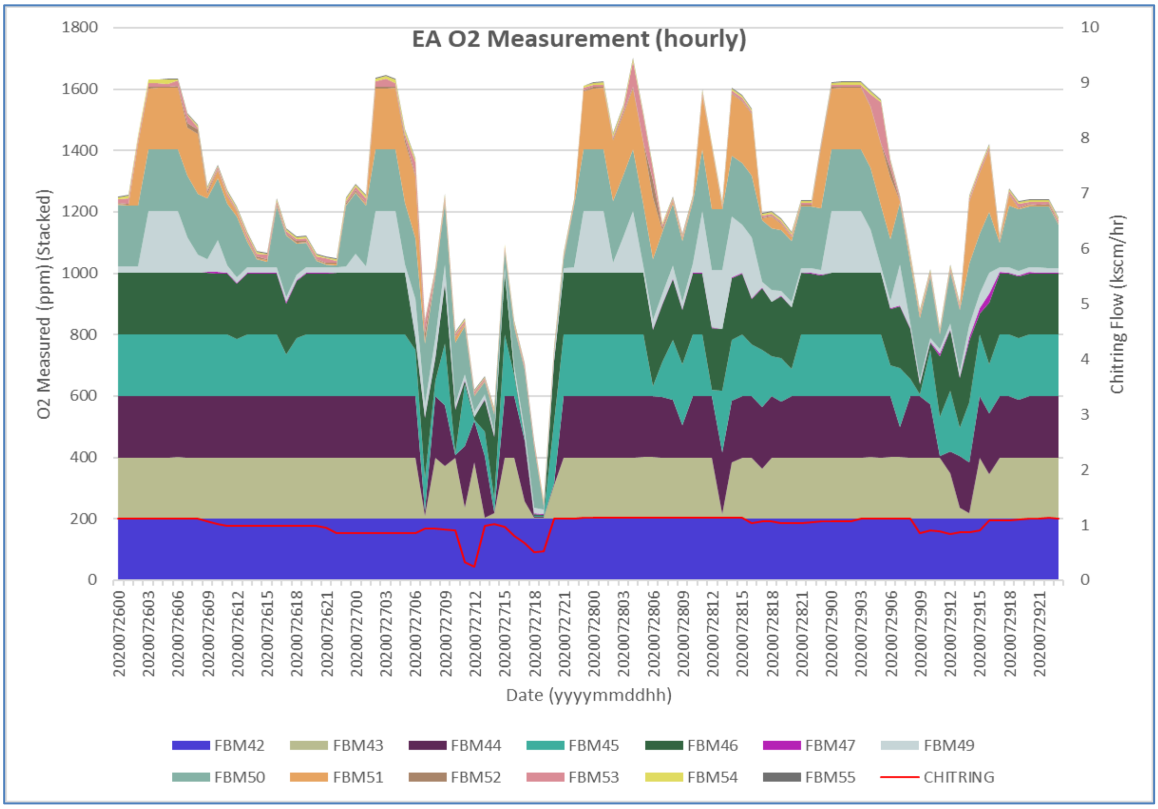

Figure 21 – Oxygen Sensor Recordings 26th – 29th July 2020 Cambridge Network

In Figure 21, it is also possible to see the impact not only of the diurnal demand, but also what happens when the flow from the biomethane reduces.

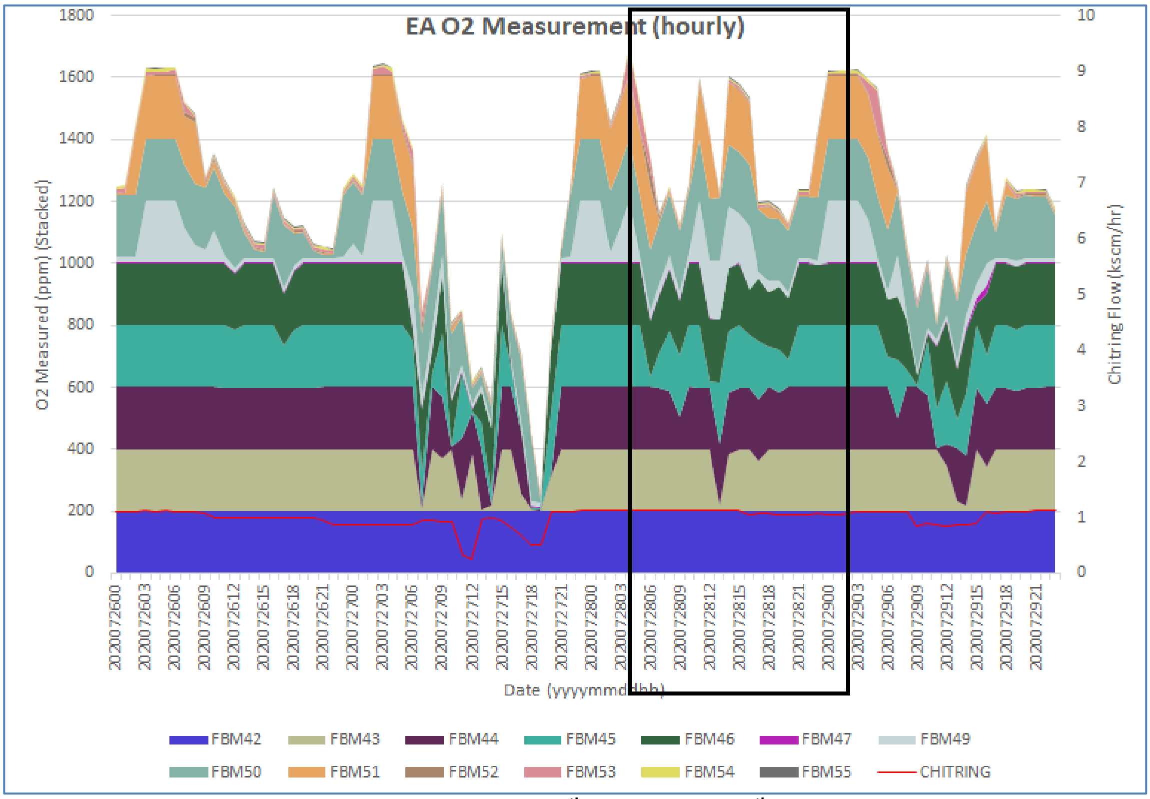

Figure 22 – Oxygen Sensor Recording 04:00 28th July - 00:00 29th July 2020 Cambridge Network

Looking at the highlighted timeslot on 28th July in Figure 22, there are fewer coloured blocks, and they are smaller in size. This timeslot covers the time of a day which is typically a time of higher consumer demand relative to the rest of the day. As demand picks up in the morning, the measured oxygen drops away from sensor number FBM45 onwards. The gas from the biomethane supply is being used by consumers closer to the entry point into the network. As this demand drops off, the number of blocks and their height increases which indicates the biomethane penetrating further into the network again.

Between '12' and '14' on 28th July, the level of oxygen measured at FBM43 drops off resulting in the stack appearing to shift down. Note that for this approximate 2-hour period, the oxygen readings at FBM42, FBM44, FBM45, FBM46, FBM49, FBM50 and FBM51 remain higher, indicating oxygen readings of around 200 ppm. The reason for the apparent fall in oxygen level at FBM43 is related to the local network dynamics with this area receiving gas from regulators supplied by both the MP biomethane and the 'NTS' feed.

Looking at the highlighted timeslot on 27th in Figure 23, the red line indicating the flow from the Chittering biomethane plant fluctuates. This reduction in gas from the biomethane supply results in fewer coloured blocks which are smaller in size; the lower volume of biomethane can only reach into a smaller area of the network.

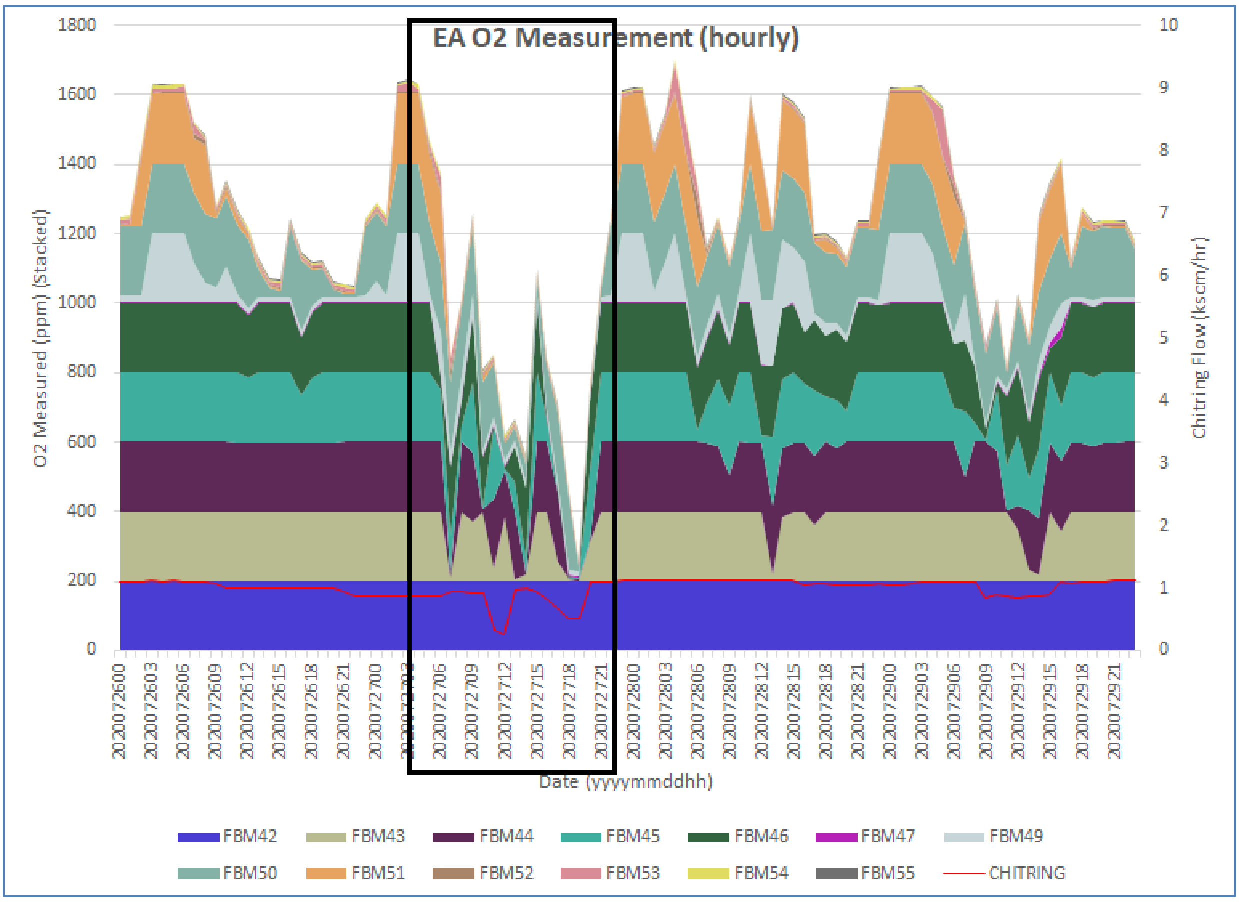

Figure 23 – Oxygen Sensor Recording 04:00-21:00 27th July 2020 Cambridge Network

This fluctuation in the hourly flow from Chittering is not a common or a daily occurrence in the site operation. The effects are smoothed out when the daily flow is considered for the generation of consumers bills; see Section 0 for further explanation on consumer billing. The frequency of such anomalies should be considered if this differs from the assumptions made when defining the Charging Area definition, as discussed in Section 9.

Figure 24 is a screen capture of the geographic view of the measured oxygen values at 03:30 on 27th July 2020 in the Cambridge network. This geographic view is the same information as that presented in Figure 21 but for the single time period of 03:30. The sensors that are nearer the biomethane entry point are shown in the darker shading representing higher readings of oxygen concentration.

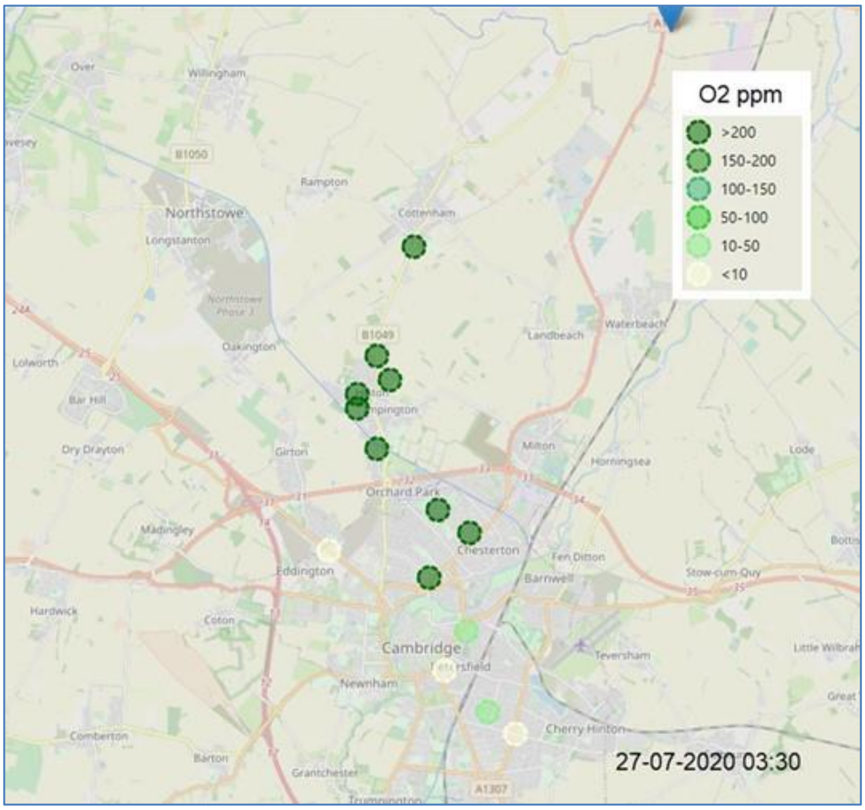

Figure 24 – Measured Oxygen 27th July 2020 03:30 Cambridge Network

Figure 25 shows the modelled oxygen ppm values for the Cambridge network at 03:30 on 27th July, the same time period as the measured values displayed in Figure 24.

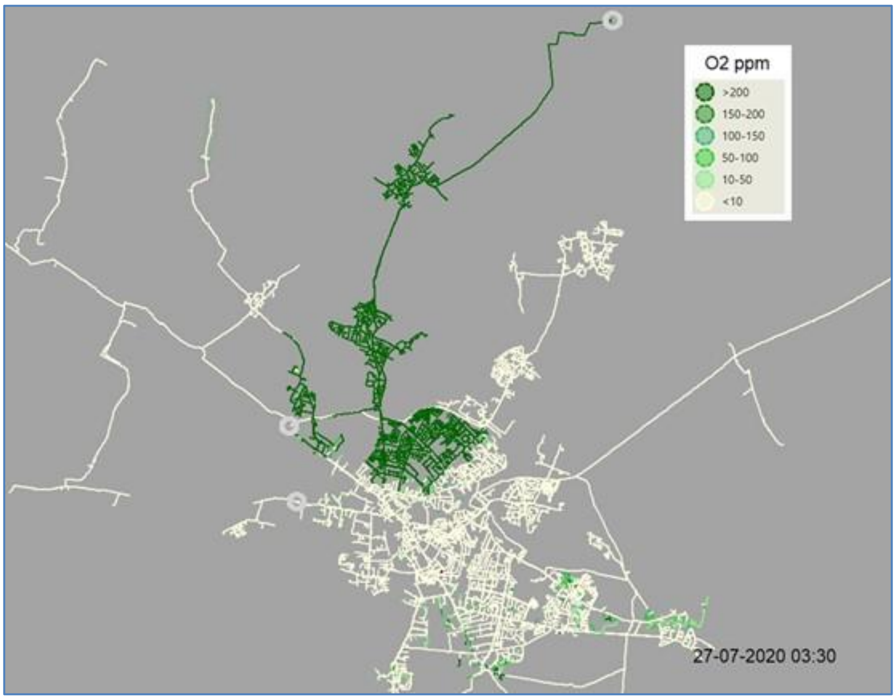

Figure 25 – Modelled Oxygen 27th July 2020 03:30 Cambridge Network

Viewing the two images overlaid, shown in Figure 26, it can be seen that the zones of concentration levels of oxygen is comparable. The spread of oxygen appears further extended in the modelled values because the modelling has coloured each pipe within the range of oxygen measurements, whereas the actual measurements were at the specific sensor locations.

It is noted that there are some small sections of modelled pipework to the south of Cambridge coloured green indicating low oxygen concentration levels. This is expected when modelling the low flow conditions as the biomethane will not dissipate out of the network as quickly as at times of higher flow. Screen captures of higher flow conditions, (comparison of data for July, September, October and January), do not present such variation.

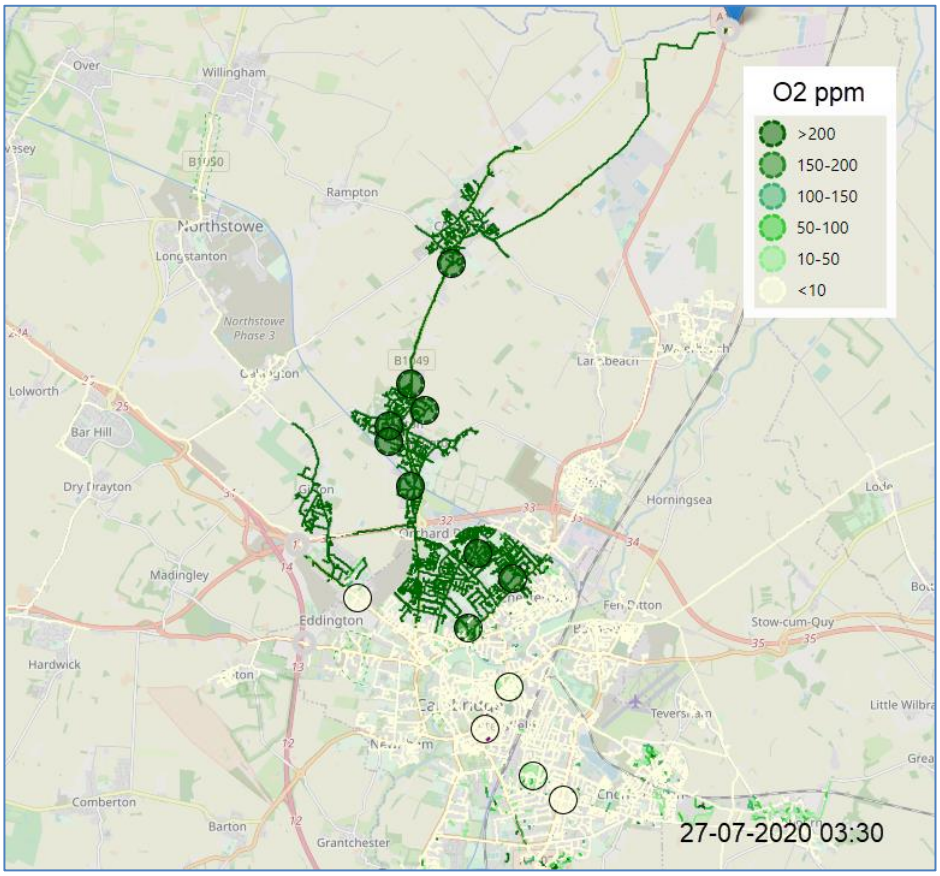

Figure 26 – Measured & Modelled Oxygen 27th July 2020 03:30 Cambridge Network

In Figure 27 the measured and modelled oxygen concentration zones are compared for another time period, 00:00 28th July 2020.

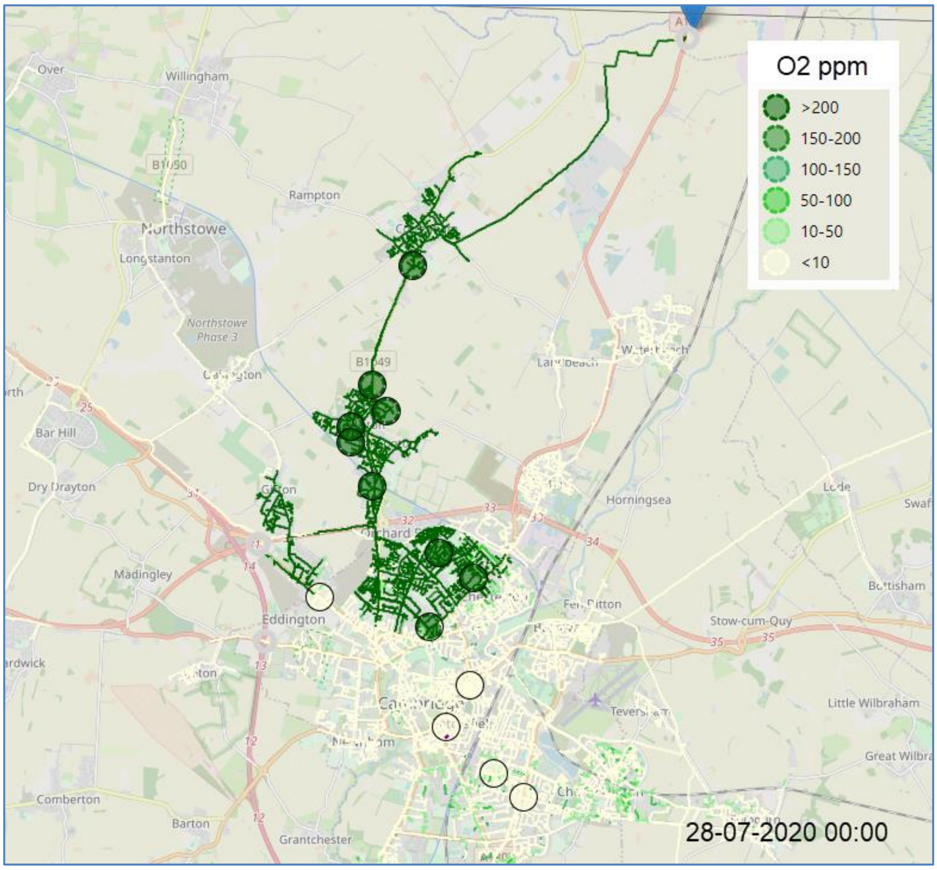

Figure 27 – Measured & Modelled Oxygen 28th July 2020 00:00 Cambridge Network

For these selected date and time periods the modelled oxygen values are comparable to the measured values demonstrating that the network model is able to show the penetration of oxygen into the wider network.

In addition to overlaying the data, the measured and modelled values of oxygen content are displayed for selected FBM sensor locations in the following figures. The network analysis modelled oxygen results (dashed line) have been displayed against the measured values (solid line). The sensors measure oxygen up to 200 ppm although the oxygen content of biomethane is much higher. The network modelling predicts the results with an averaged oxygen value of 2400 ppm being fed into the network at Chittering.

The sensor data has measured the specific behaviour of the instantaneous effects of the actual demand and its effects in the localised pipes. In contrast, the network modelling uses an average generic demand profile which generates results which are similar, though not the exactly the same as those experienced. In simple terms, the localised instantaneous effect of, for example, a house boiler turning on, cannot be replicated through the averaging techniques applied in industry accepted low pressure modelling. If this data was available on an individual consumer basis then it would be possible to assess the network behaviour in more detail.

In Figure 28 below, the measured (solid line) and modelled (dashed line) oxygen ppm concentration values at FBM44 are compared. The modelled values are an indication of what could be being seen on the actual network. At this location the modelled oxygen values are significantly higher than the capped measured value, as shown in Figure 29.

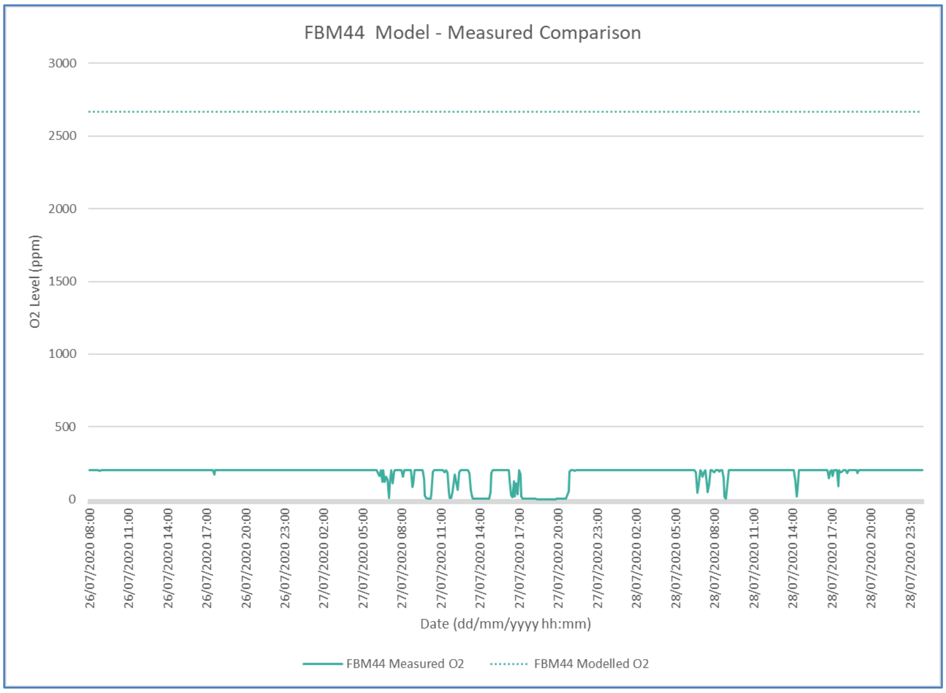

Figure 28 – FBM44 Measured & Modelled Comparison 26th - 29th July 2020

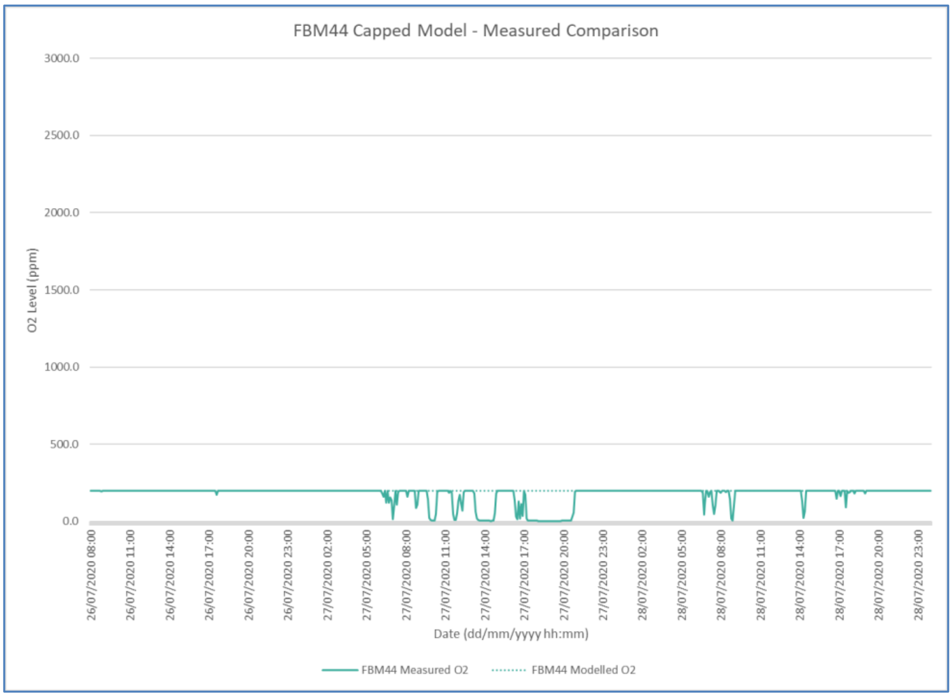

Figure 29 – FBM44 Measured & Capped-Modelled Comparison 26th - 29th July 2020

The modelling results for FBM44 shows comparable values the majority of the time, with the largest discrepancy at 17:00 on 27th July. It is noted that between 17:00 and 20:00 there is a drop in the flow rate from Chittering and the oxygen content was averaging 1400 ppm. If this level of oxygen content were modelled there would be a corresponding drop in oxygen levels across the network.

Figure 30 provides a comparison of three further sensor points.

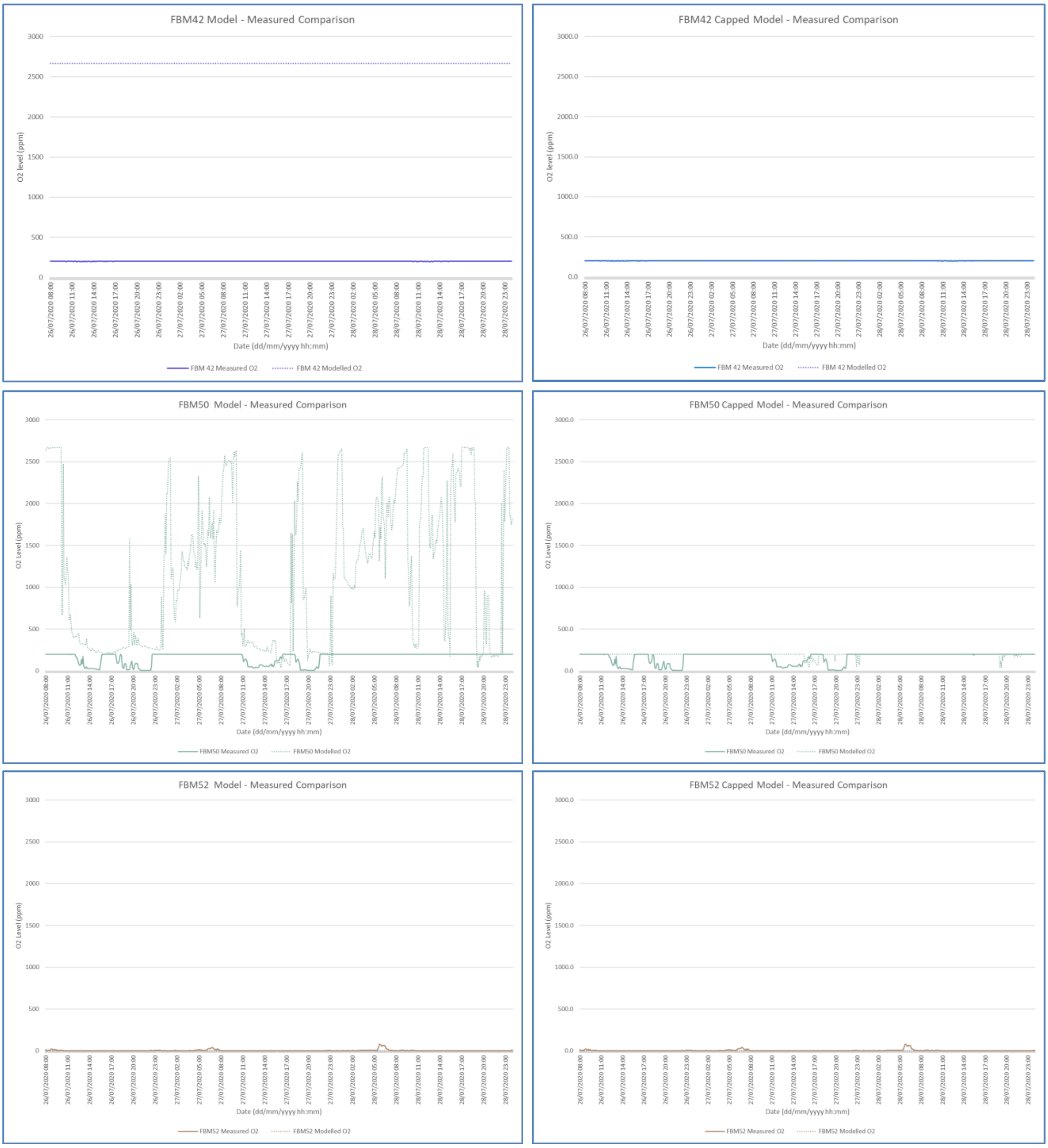

Figure 30 – Measured & Modelled and Measured & Capped-Modelled Comparisons for Selected FBM Sensors 26th - 29th July 2020

In all 4 selected charts, over the period of detailed modelling, there is a strong correlation between the pattern of measured and modelled oxygen readings. There is a slight misalignment in the timing of the rises and falls in some of the values which is likely due to a combination of factors including data timestamp shift and gas transit times from the gas main to the oxygen sensor.

As described above the sensor data has measured the impact of the specific customer demand. Network modelling seeks to predict the overall behaviour of the network with a generic demand profile.

The network analysis model has generated results which are similar to the measured oxygen values; a strong correlation. This demonstrates that the network model is able to show the penetration of oxygen into the wider network.

6.2.2 Wednesday 26th – Saturday 29th September 2020

Figure 31 shows the stacked view of the hourly oxygen readings for the period 26th – 29th September 2020. The data shows that over the period of the time, some, though not all sensors were recording oxygen levels of 200 ppm. This means that the biomethane was at times penetrating further into the network as seen by the cumulative height of the individual FBM sensors.

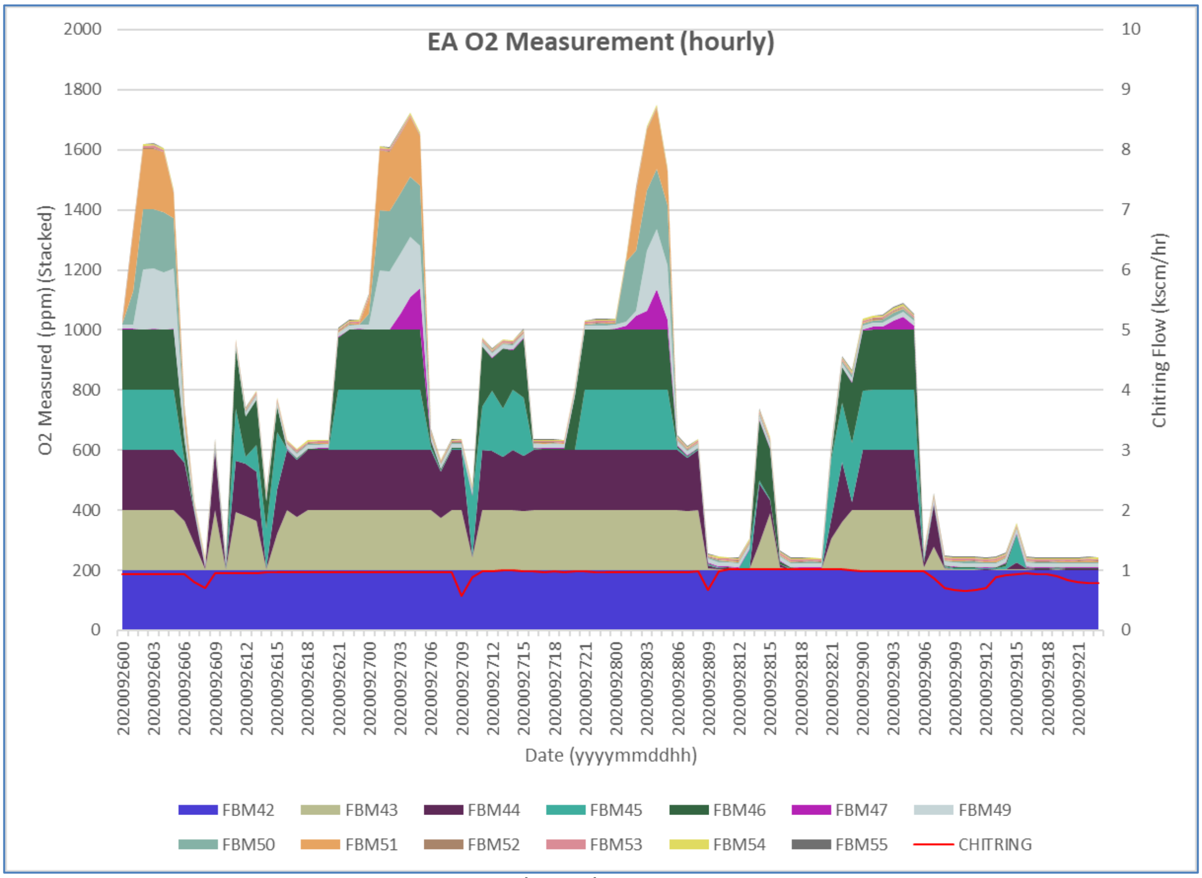

Figure 31 – Oxygen Sensor Recordings 26th – 29th September 2020 Cambridge Network Street Sites

As with the time period in July, in Figure 31, it is also possible to see the impact not only of the diurnal demand, but also what happens when the flow from the biomethane entry point reduces.

Looking at the daily timeslots that end in '06' through to '21' there are fewer coloured blocks, and they are smaller in height. This timeslot covers the time of a day which is typically a time of higher consumer demand relative to the rest of the day. As demand picks up in the morning, the measured oxygen drops away, and is primarily only seen at FBM42 during higher demand periods. The gas from the biomethane supply is being used by consumers much closer to the entry point into the network. As this demand drops off, the number of blocks and their height increases again.

Looking at the timeslot 06 onwards on 29th, the red line indicating the flow from the Chittering biomethane plant drops. This reduction in gas from the biomethane supply results in fewer coloured blocks which are significantly smaller in height; the lower volume of biomethane can only reach into a much smaller area of the network.

Figure 32 is a screen capture of the geographic view of the measured oxygen values at 03:00 on 27th September 2020 in the Cambridge network overlaid on the model with the modelled oxygen values for the same time period. Viewing the measured and modelled values together it can be seen that the zone of the concentration of oxygen is comparable.

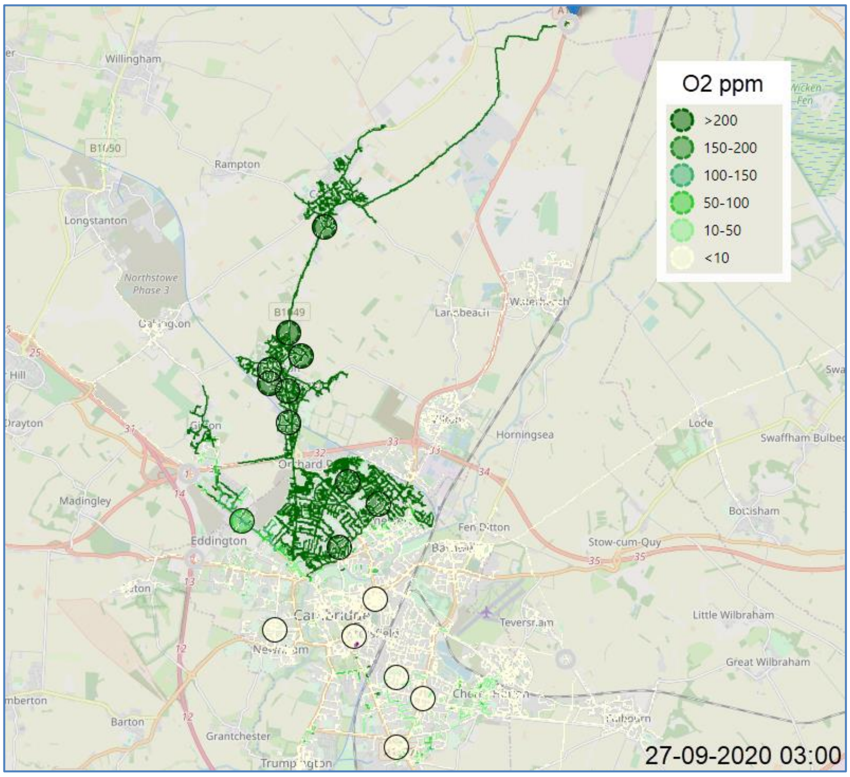

Figure 32 – Measured & Modelled Oxygen 03:00 27th September 2020 Cambridge Network

For a different time, 15:00 on 27th September 2020, Figure 33 has the measured and modelled oxygen results overlaid; the zone of the concentration of oxygen is comparable.

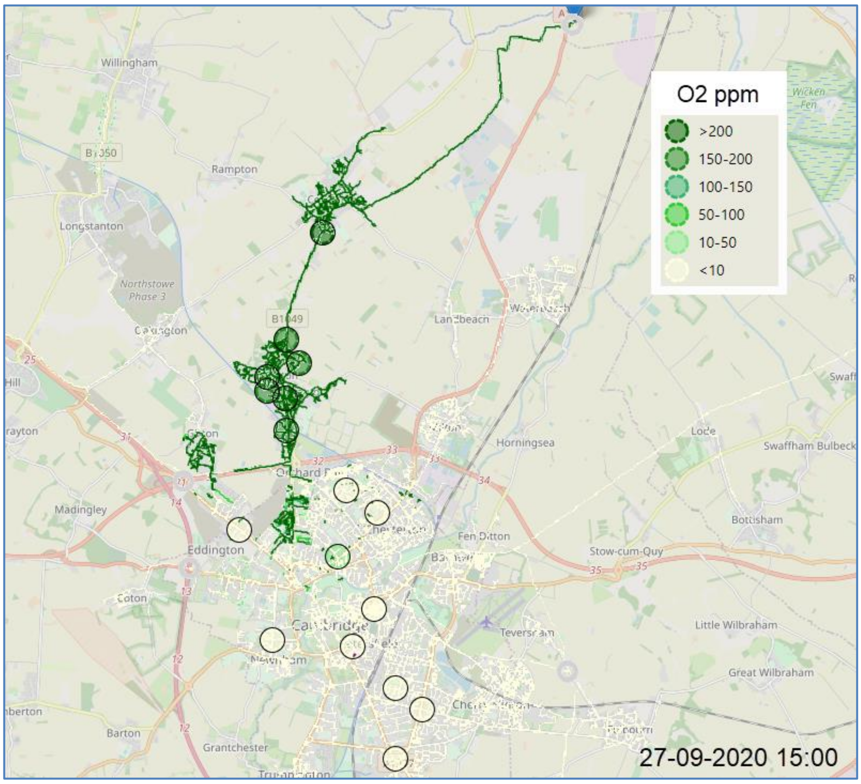

Figure 33 – Measured & Modelled Oxygen 15:00 27th September 2020 Cambridge Network

For a different time, 06:30 on 28th September 2020, Figure 34 has the measured and modelled oxygen results overlaid; the zone of the concentration of oxygen is comparable.

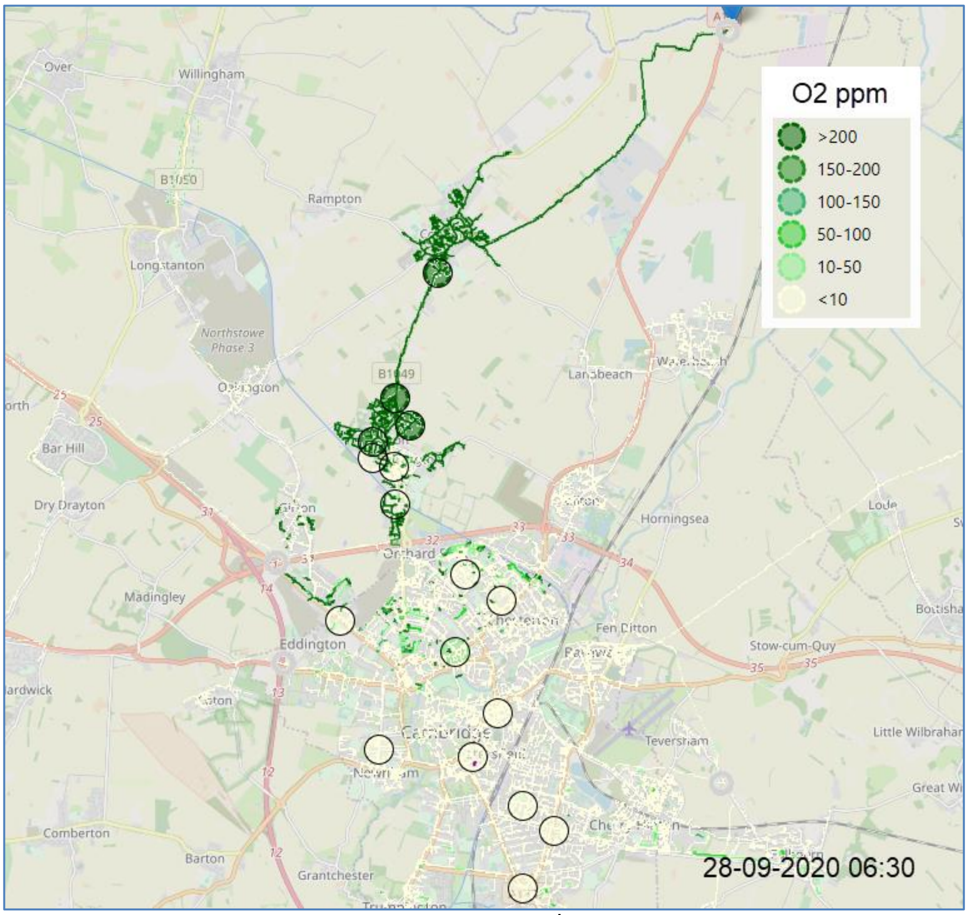

Figure 34 – Measured & Modelled Oxygen 06:30 28th September 2020 Cambridge Network

In addition to the overlaying data, the measured and modelled values of oxygen content are displayed for selected FBM sensor locations in the following figures. The network analysis modelled oxygen results (dashed line) have been displayed against the measured values (solid line).

In Figure 35 below, the measured (solid line) and modelled (dashed line) oxygen ppm concentration values at FBM43, FBM47 and FBM50 are compared. The modelled values are an indication of what could be being seen on the actual network. As with the data for the July model, the modelled results follow a similar time profile as the measured data and are comparable values the majority of the time.

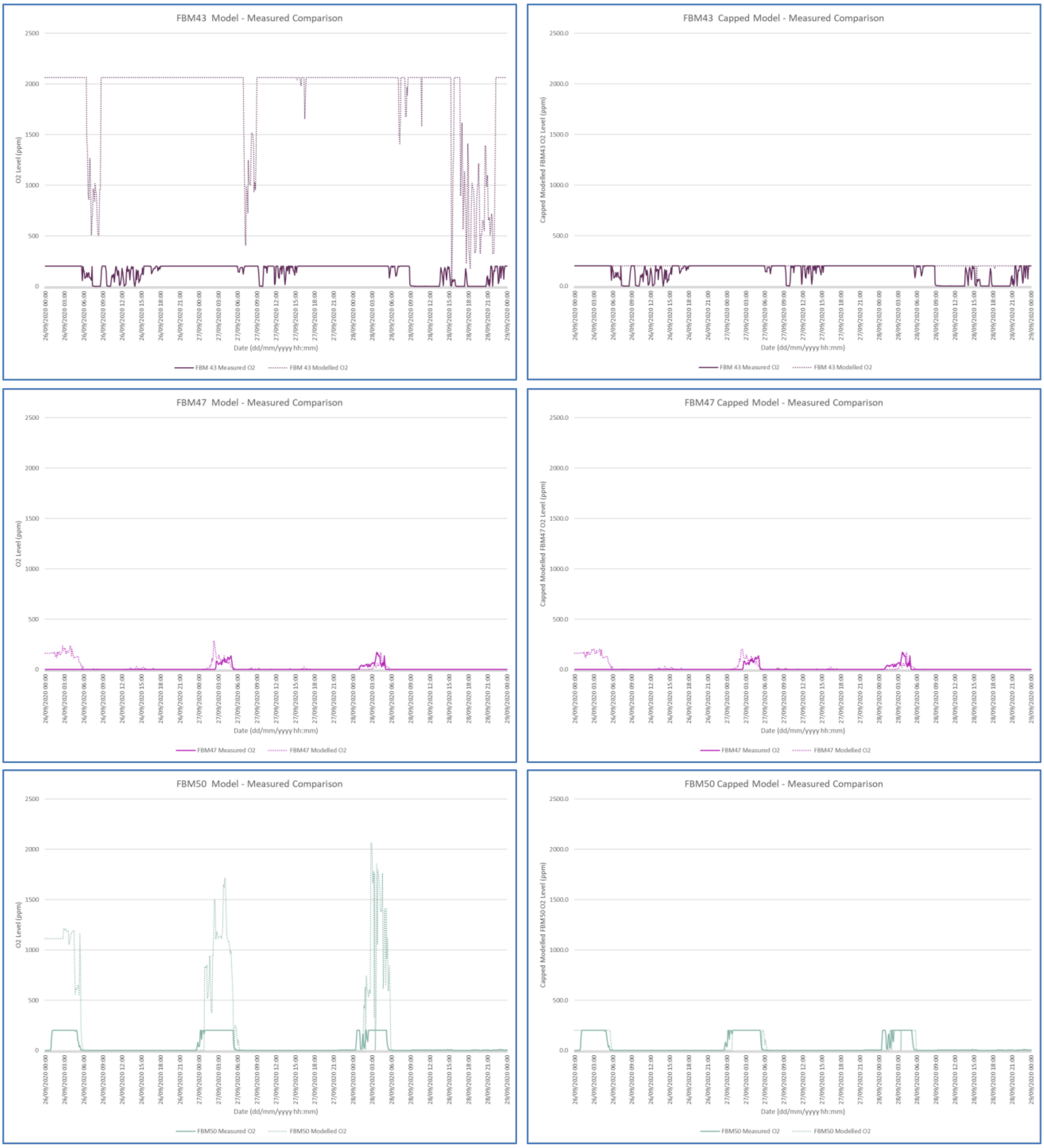

Figure 35 – Measured & Modelled and Measured & Capped-Modelled Comparisons for Selected FBM Sensors 26th - 29th September 2020

In all 3 selected charts, over the period of detailed modelling, there is a strong correlation between the pattern of measured and modelled oxygen readings. As with the data for July, the sensor data reflects the impact of specific customer demand. Whereas network modelling seeks to predict the overall behaviour of the network with a generic demand profile.

The network analysis model has generated results which are similar to the measured oxygen values; a strong correlation. This demonstrates that the network model is able to show the penetration of oxygen into the wider network.

6.2.3 Monday 26th – Thursday 29th October 2020

Figure 36 shows the stacked view of the hourly oxygen readings for the period 26th – 29th October 2020. The data shows that over the period of the time, some sensors were recording oxygen levels of 200 ppm. Compared with the data in Figure 21 and Figure 31, the overall number of sensors recording oxygen levels of 200 ppm is less and the overall height of the stack is smaller. This means that the biomethane was not penetrating as far into the network during this period in October compared with both periods in July and September.

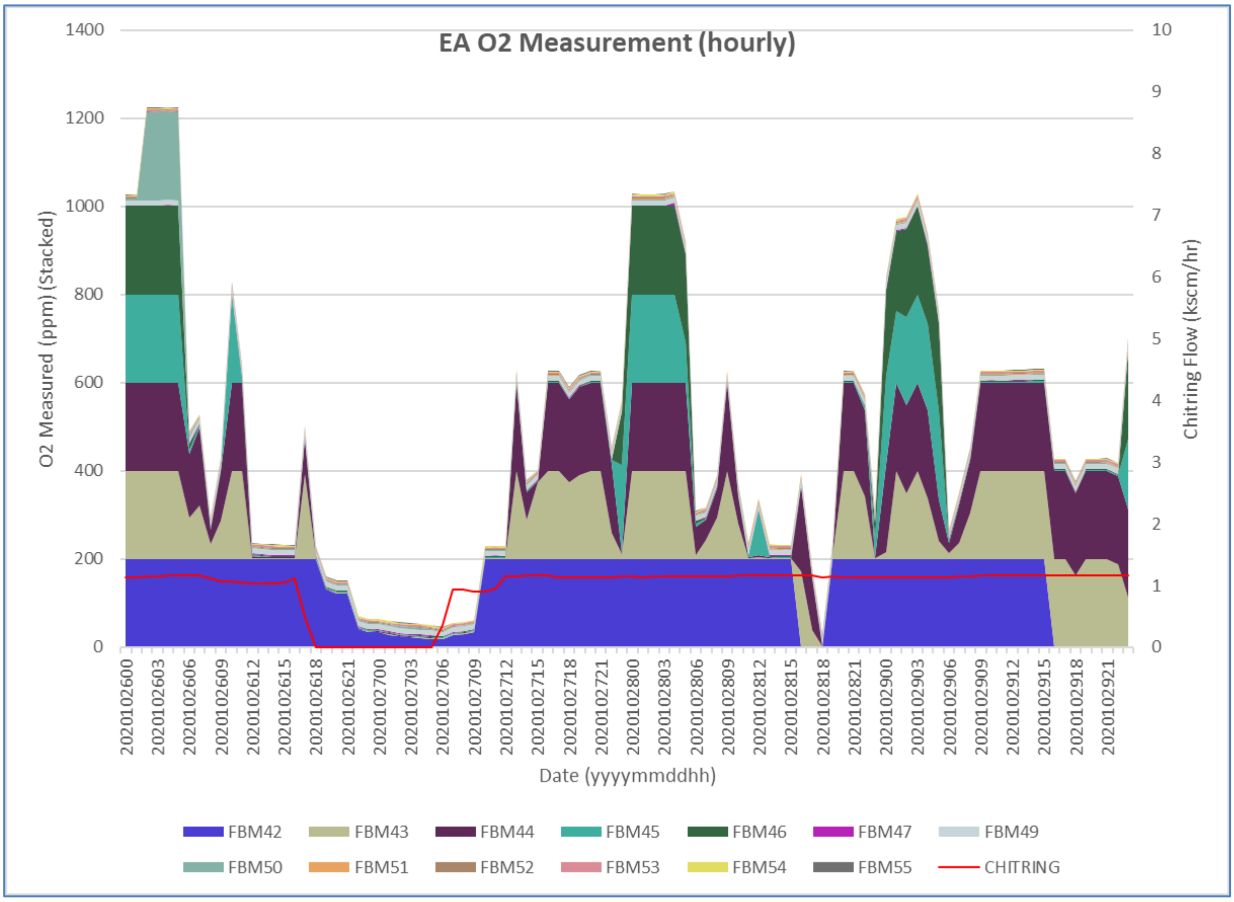

Figure 36 – Oxygen Sensor Recording 26th – 29th October 2020 Cambridge Network

In Figure 36, it is also possible to see the impact not only of the diurnal demand, but also more clearly what happens when the flow from the biomethane reduces / stops, as seen between '15' on 26th and '06' on 27th October.

Figure 37, Figure 38, Figure 39 and Figure 40 are screen captures of the geographic view of the measured oxygen values at specific timeslot with the Cambridge network modelled oxygen values overlaid for the same time period. The darker the colouring of both the sensors and pipes represent higher readings of oxygen concentration. Viewing the measured and modelled values together it can be seen that the zone of the concentration of oxygen is comparable.

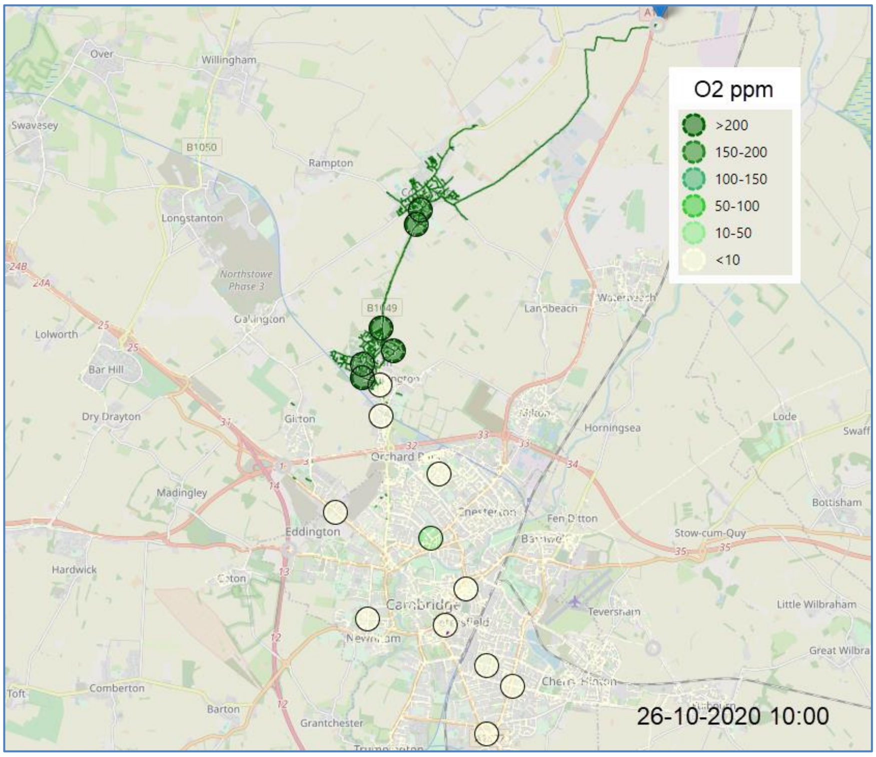

Figure 37 – Measured & Modelled Oxygen 10:00 26th October 2020 Cambridge Network

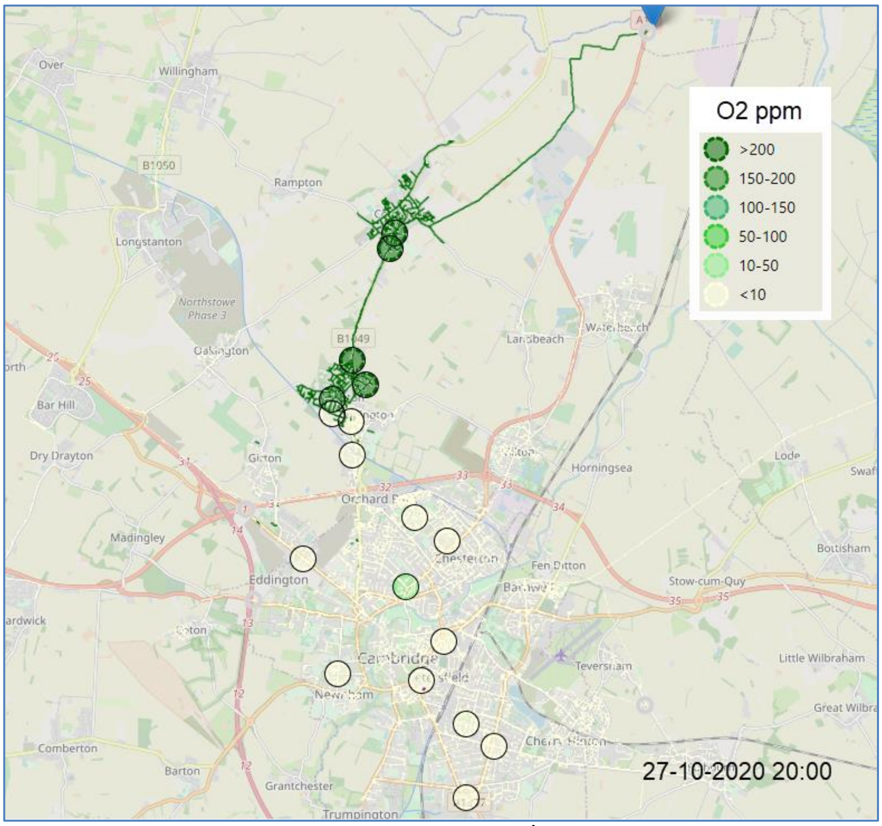

Figure 38 – Measured & Modelled Oxygen 20:00 27th October 2020 Cambridge Network

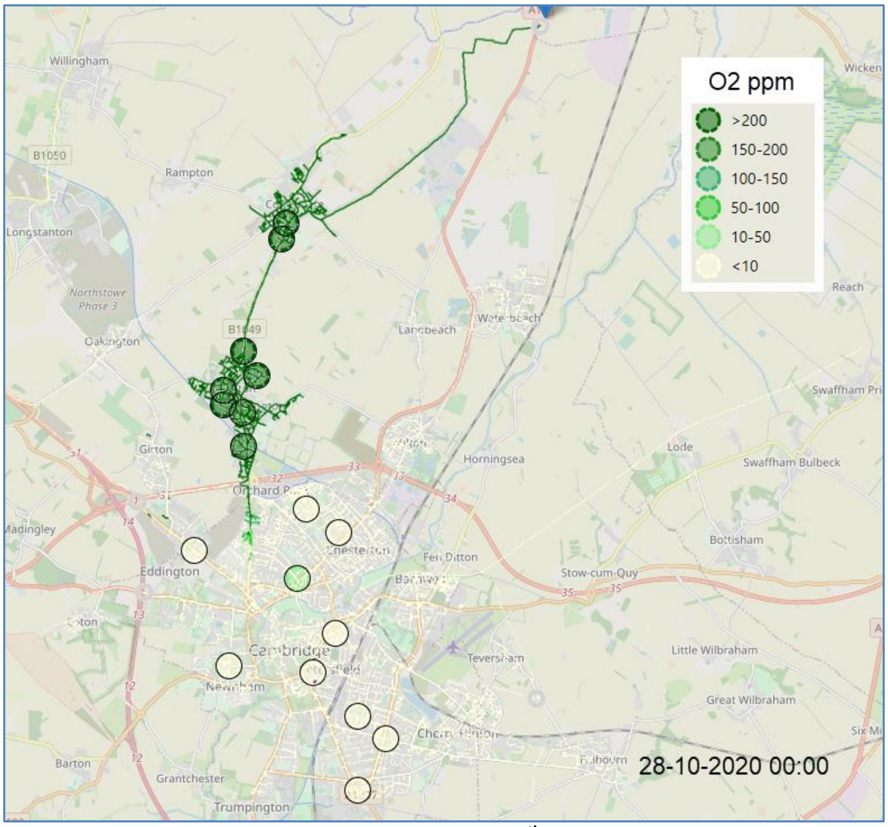

Figure 39 – Measured & Modelled Oxygen 00:00 28th October 2020 Cambridge Network

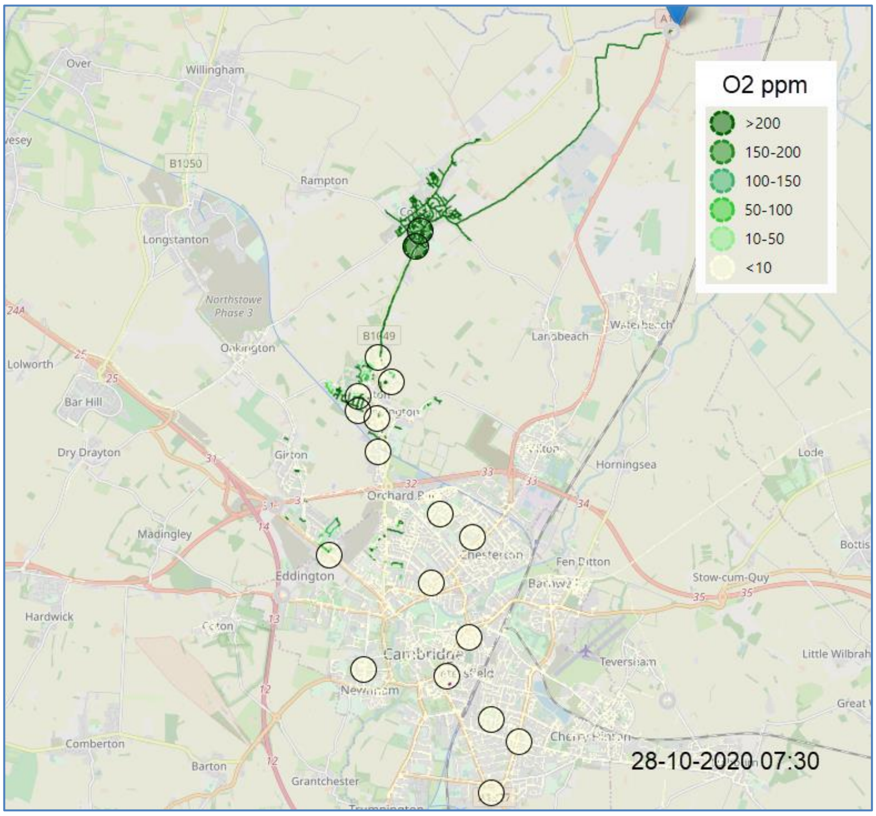

Figure 40 – Measured & Modelled Oxygen 07:30 28th October 2020 Cambridge Network

In addition to the overlaying data, the measured and modelled values of oxygen content are displayed for selected FBM sensor locations in the following figures. The network analysis modelled oxygen results (dashed line) have been displayed against the measured values (solid line).

Figure 41 – Measured & Modelled and Measured & Capped-Modelled Comparisons for Selected FBM Sensors 26th - 29th October 2020

In all 3 selected charts, over the period of detailed modelling, there is a strong correlation between the pattern of measured and modelled oxygen readings. As with the data for July and September, the sensor data reflects the impact of specific customer demand. Whereas network modelling seeks to predict the overall behaviour of the network with a generic demand profile.

The network analysis model has generated results which are similar to the measured oxygen values; a strong correlation. This demonstrates that the network model is able to show the penetration of oxygen into the wider network.

6.2.4 Thursday 7th – Friday 8th January 2021

Figure 42 shows the stacked view of the hourly oxygen readings for the period 7th – 8th January 2021. The data shows that over the period of the time, some, though not many sensors were recording oxygen levels of 200 ppm. Note: there were issues with the recording of data for FBM42; it starts recording at 18:48 on 7th January. The data shows that compared to earlier months; the gas was not penetrating far into the network as the cumulative height of the individual FBM sensors is small.

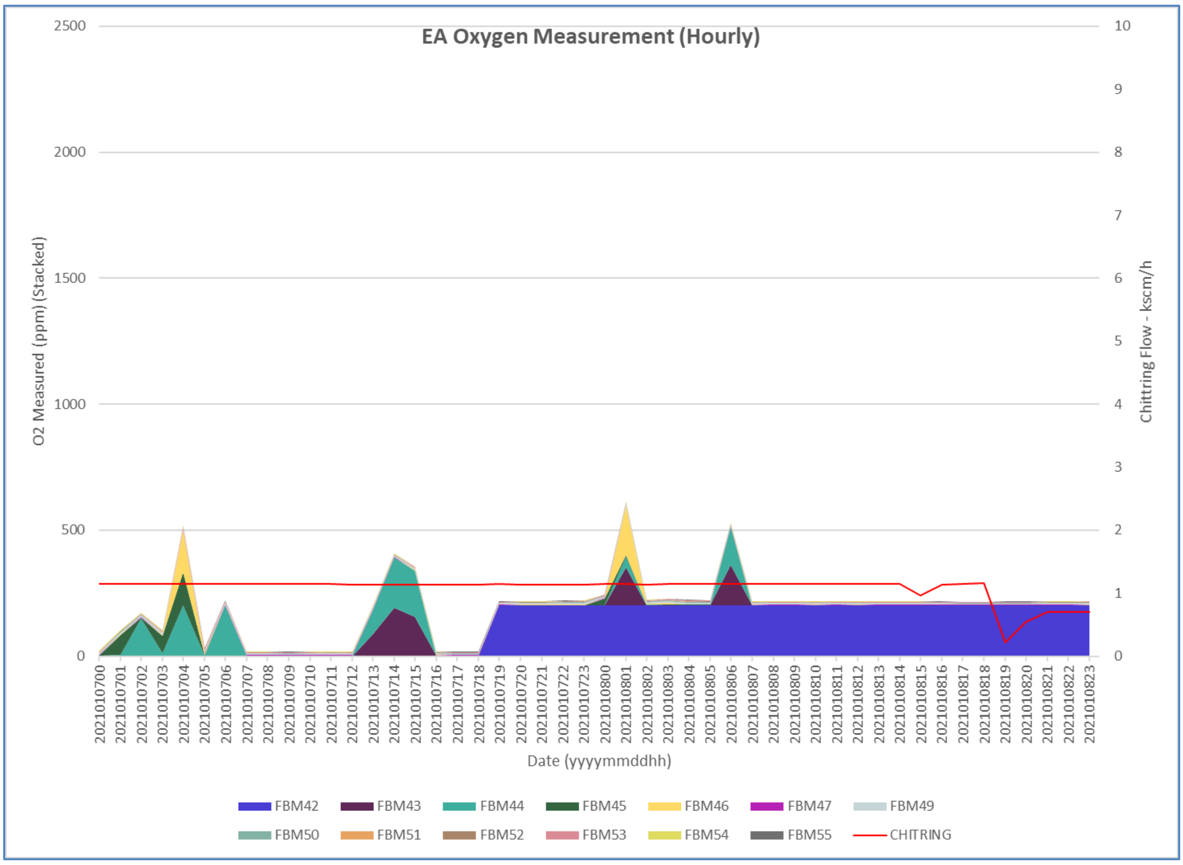

Figure 42 – Oxygen Sensor Recordings 7th – 8th January 2021 Cambridge Network

Figure 43 and Figure 44 are screen captures of the geographic view of the measured oxygen values at specific timeslot for the January 2021 model in the Cambridge network overlaid on the model with the modelled oxygen values for the same time period. Only the northern section of the model has been shown as the oxygen readings for the remaining sensors were constantly reading zero. The darker the colouring of both the sensors and pipes represent higher readings of oxygen concentration. Viewing the measured and modelled values together it can be seen that the zone of the concentration of oxygen is comparable.

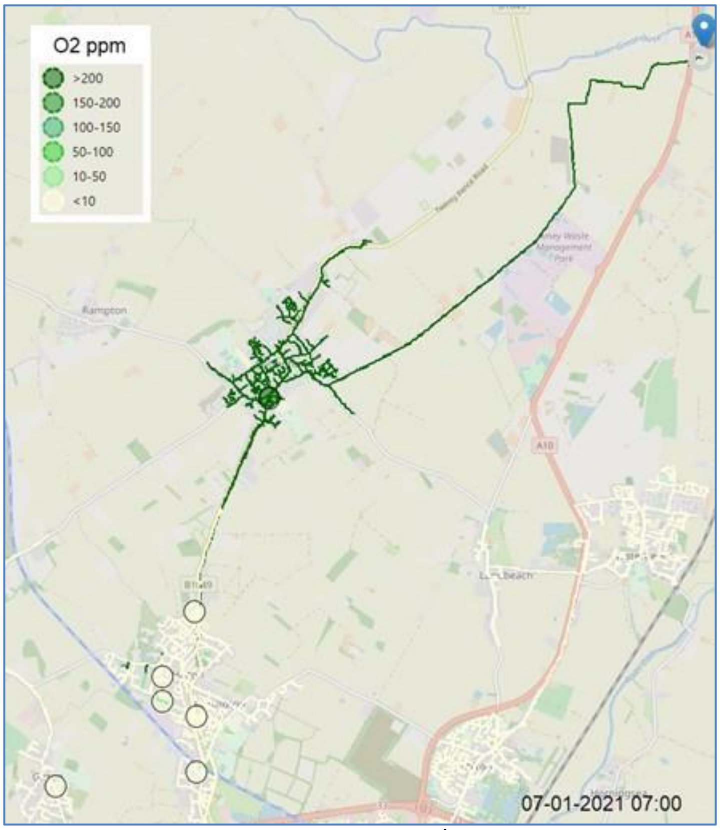

Figure 43 – Measured & Modelled Oxygen 07:00 7th January 2021 Cambridge Network

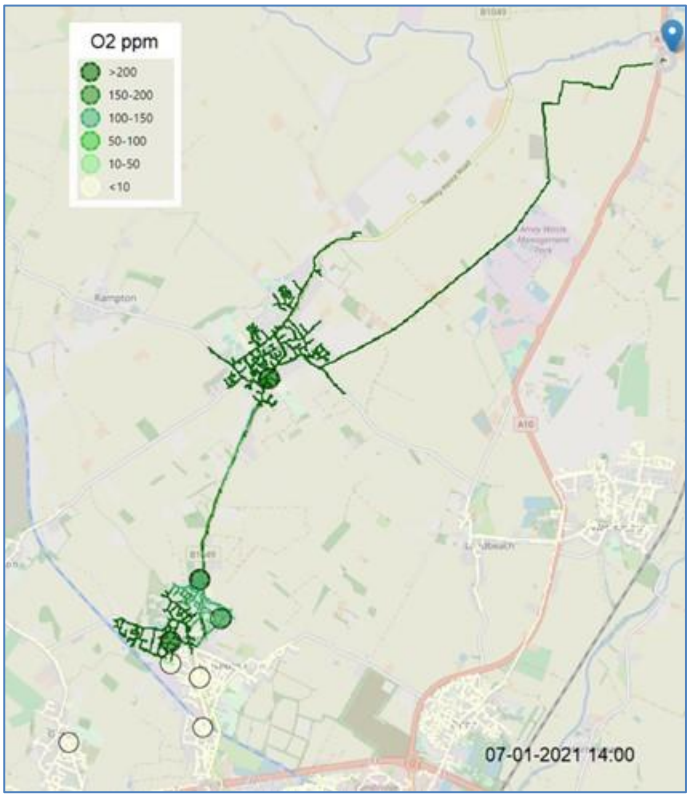

Figure 44 – Measured & Modelled Oxygen 14:00 7th January 2021 Cambridge Network

In addition to the overlaying data, the measured and modelled values of oxygen content are displayed for selected FBM sensor locations in the following figures. The network analysis modelled oxygen results (dashed line) have been displayed against the measured values (solid line).

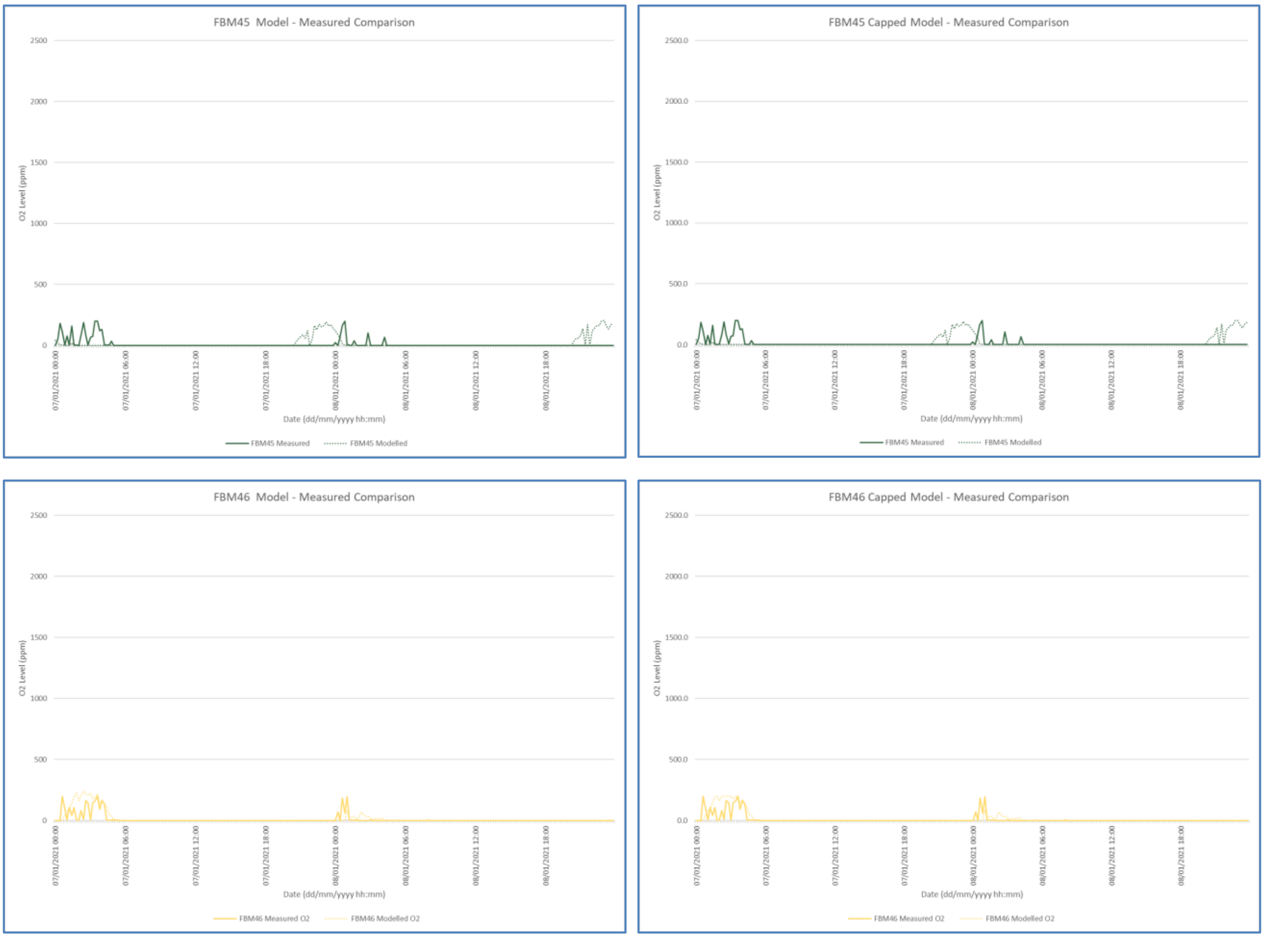

Figure 45 – Measured & Modelled and Measured & Capped-Modelled Comparisons for Selected FBM Sensors 7th – 8th January 2021

In the two selected charts, over the period of detailed modelling, there is a strong correlation between the pattern of measured and modelled oxygen readings. As with the data for July, September and October, the sensor data reflects the impact of specific customer demand. Whereas network modelling seeks to predict the overall behaviour of the network with a generic demand profile.

The network analysis model has generated results which are similar to the measured oxygen values; a strong correlation. This demonstrates that the network model is able to show the penetration of oxygen into the wider network.

6.3 Modelling of Lincolnshire Network

6.3.1 Monday 26th – Thursday 29th October 2020 – Steady State Analysis

For the Lincolnshire network, a detailed comparison of the oxygen data has been undertaken using the steady state network analysis software GBNA. The LDZ demand conditions for the period Monday 26th – Thursday 29th October 2020 calculates to approximately 48% 1:20 Forecast Peak Day Demand 2020-21 EM LDZ.

Figure 46 show the stacked view of the oxygen measurements within the Lincolnshire network for selected time period. The data shows that over the period of the time, some sensors were recording oxygen levels of 200 ppm. There is a clear diurnal profile with the number of sites recording oxygen (height of the stack) increasing during the early hours of each day.

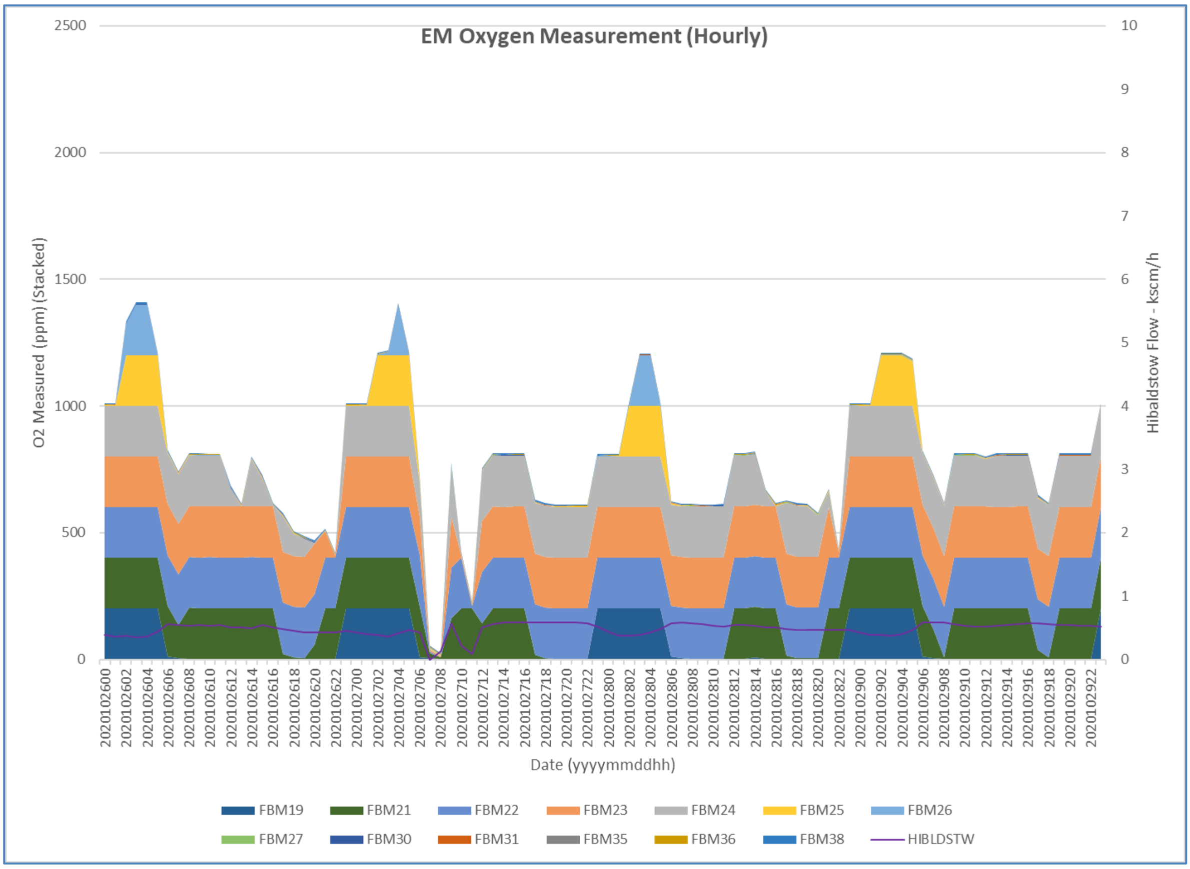

Figure 46 – Oxygen Sensor Recordings 26th – 29th October 2020 Lincolnshire Network

For the steady state analysis comparison, a period of high demand over the selected dates was chosen, 17:00 on 28th October. The functionality within GBNA is not designed for transient analysis and transient tracing of gases. However, it is capable of modelling the zones of influence of zones of interaction of sources and regulators. This functionality has been used to show how the network analysis model can provide a reliable correlation with the recorded zone of influence of the biomethane gas entry at Hibaldstow. The following comparisons are based modelling the network parameters indicative of the conditions at 17:00 on 28th October 2020.

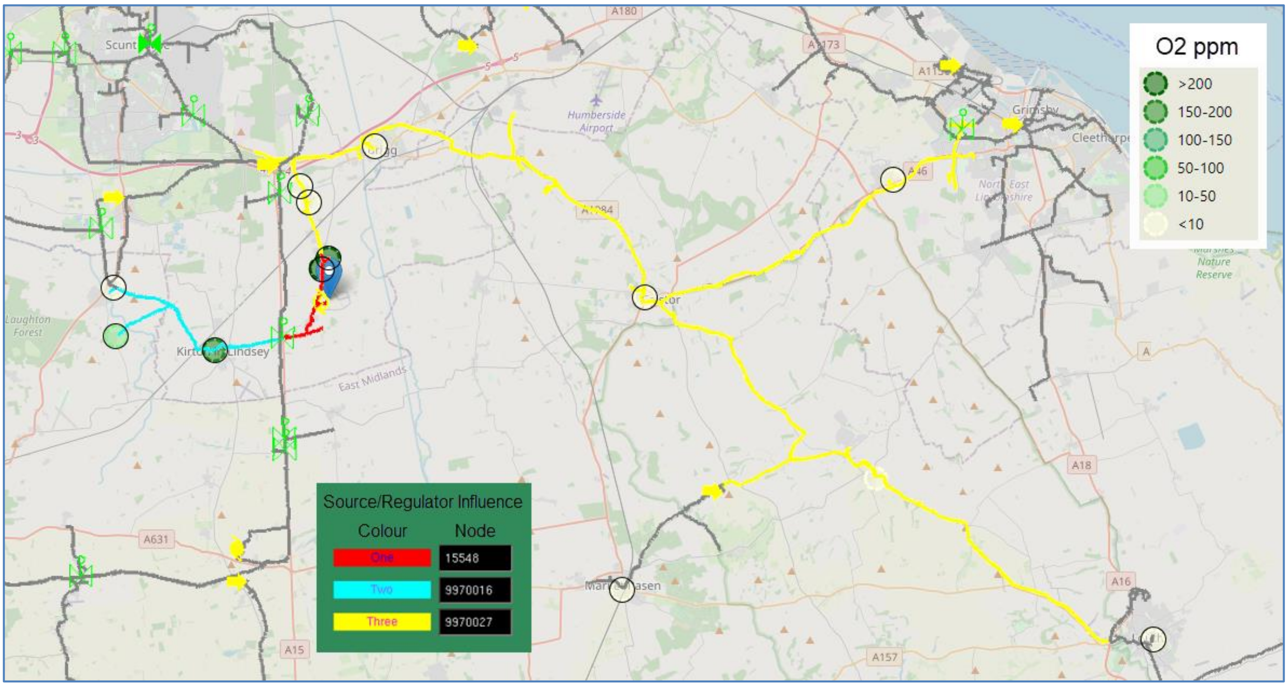

Figure 47 – Measured Oxygen and Modelled Zone of Influence 17:00 28th October 2020 Lincolnshire Network

Figure 47 shows an extract of the network analysis model with the network pipes coloured by the dominant source of gas, overlaid on the geographic view of the measured oxygen values. From this figure it can be seen that the gas from Hibaldstow (coloured in red) interacts with the medium pressure source from the north (identified as 9970027 in yellow) and the IP to MP regulator to from the south (identified as 9970016 in light blue). While the current functionality within GBNA is not designed for the tracing of specific gas properties, the zone of influence analysis does allow a comparison of the measured values of Oxygen from the biomethane gas and the modelled zone of influence of the biomethane source.

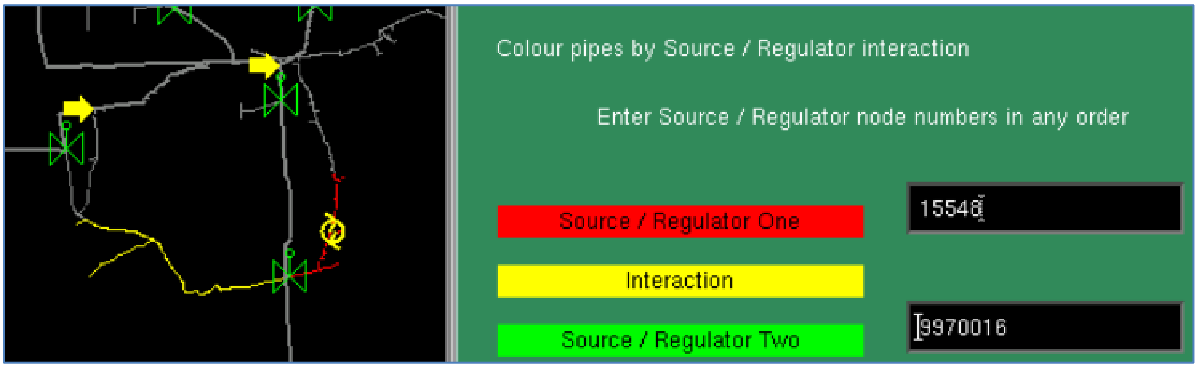

Figure 48 – Modelled Zone of Interaction Between Two Selected Sources/Regulators 17:00 28th October 2020 Lincolnshire Network

Figure 48 shows an extract of the network analysis model with the network pipes coloured by the zone of interaction between two selected sources / regulators. From this figure it can be seen that the gas from Hibaldstow (coloured in red) extends to the point of interaction with the IP to MP regulator to from the south (identified as 9970016). From this point the pipes are coloured yellow indicating interaction with the gas from the regulator 9970016. There are no pipes coloured in green indicating there are no pipes solely supplied by gas from the regulator 9970016 under these modelled conditions.

6.3.2 Comparison of Different Demand Periods

The following stacked views provide a summary of the measured levels of oxygen at different times of the year which represent contrasting periods of overall demand.

Figure 49 shows the oxygen recordings for September 2020. For the majority of the time the coloured blocks are greater in number and taller in size and contributing to a greater overall stack height. This demonstrates that the biomethane has travelled further into the network.

Figure 50 shows the oxygen recordings for January 2021. Compared to the data from September (Figure 49), as the biomethane is absorbed closer to the point of entry, there are fewer sensors receiving oxygen and a reduced concentration of oxygen where it is measured. This shows the penetration of biomethane into the network is reduced during periods of higher demand.

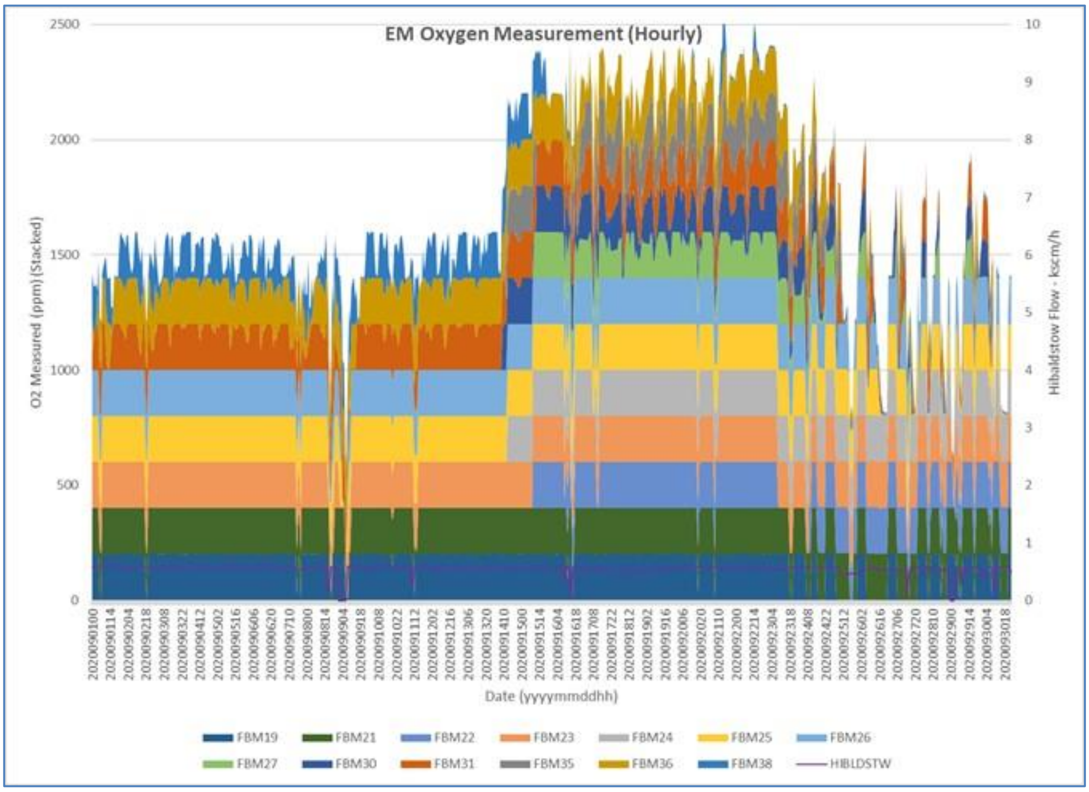

Figure 49 – Oxygen Sensor Recordings September 2020 Lincolnshire Network

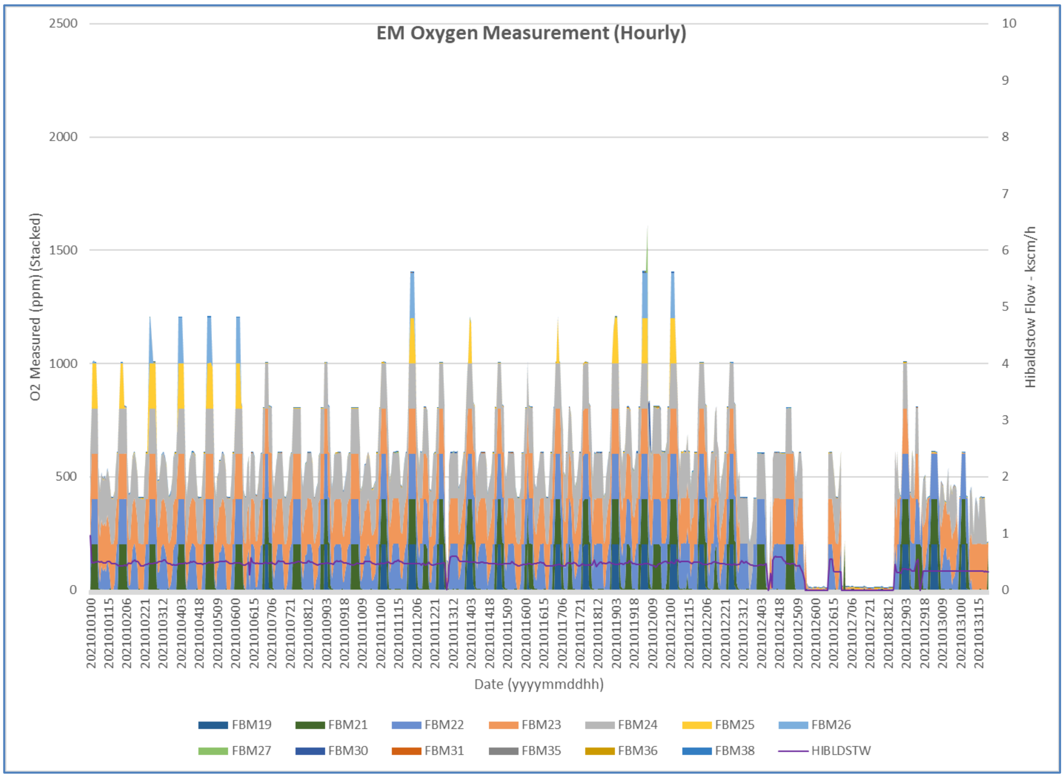

Figure 50 – Oxygen Sensor Recordings January 2021 Lincolnshire Network

The data in Figure 49 and Figure 50 demonstrates that there is both a seasonal and diurnal variation in the penetration of biomethane across the Lincolnshire network.

The stack heights of individual sensors i.e., the number of locations receiving biomethane and the proportion of biomethane in any gas mixture in the winter months are lower compared to the summer months. As the biomethane from Hibaldstow is absorbed closer to the point of entry, there are fewer sensors receiving oxygen and a reduced concentration of oxygen where it is measured. This confirms that the penetration of biomethane into the network is reduced during periods of higher demand.

6.4 Accuracy of the Modelling of Oxygen Content

The analysis of measured versus modelled biomethane presence was carried out using base data at a 6-minute granularity. This was aggregated up to the hourly level in the calculations. Whilst billing calculations are carried out at a daily level, the most robust statistical analysis can be obtained by maximising the number of data points, and the longer the time base used, the fewer data points are available. A number of different time bases were assessed, and hourly was chosen as the optimal one that gave sufficient stability in the readings whilst providing as many data points as possible for the analysis.

The presence of biomethane was detected using the Oxygen content of the gas at each monitoring point in the network. Natural gas has a maximum Oxygen content of 10ppm (see section 3.2.1), and the sensors have been tested to an accuracy of ±10% of reading +2ppm. As such, a measurement of 14ppm or above was regarded as a reading showing a definitive presence of biomethane (an approach which incorporates a small level of additional contingency).

The analysis is therefore centred on those locations and times where biomethane is definitely present according to the above rules. This approach provides a clean dataset against which to assess the quality of the network modelling. Any Oxygen measurements below 14ppm are discarded because all of the experimental uncertainty has been placed in this set of points: they may or may not include the presence of biomethane, and as such are not suitable for a robust analysis.

In order to conduct the test at the hourly level, each individual 6-minute period in any given hour was examined, and a positive identification of measured biomethane in any of them results in a positive for the hour. An equivalent process was carried out for modelled Oxygen content, and the proportion of hours for which the model successfully predicted the presence of biomethane was calculated for each monitoring point. In addition, the average measured Oxygen content at each site was also calculated. The results for the Cambridge network are given in tabular and graphical form in Table 5 and Figure 51. below. Only monitoring points with positive biomethane detections are included.

Monitoring Point	Average measured O2 Concentration (ppm)	Model Accuracy
FBM42	191.9	91.2%
FBM43	110.1	96.6%
FBM44	107.4	100.0%
FBM45	79.6	92.4%
FBM46	79.3	96.8%
FBM47	4.3	81.8%
FBM49	38.1	80.9%
FBM50	66.8	92.0%
FBM51	32.7	93.3%
FBM52	3.1	0.0%
FBM53	6.8	0.0%

Table 5 – Model Accuracy in Predicting Presence of Biomethane in the Cambridge Network

It can be seen from these figures that for the vast majority of monitoring points where biomethane was detected, the model is highly successful in reflecting this. As would be expected, the average Oxygen concentrations are highest for those points nearest to the biomethane supply, and drops as the biomethane travels through the network and mixes with other gas. The model maintains its accuracy through to very low Oxygen concentrations, even achieving an accuracy of 81.1% for FBM47, which has an average Oxygen concentration of 4.3ppm. Note that these average concentrations are across all time periods (including those where no biomethane was detected) and hence an average reading of less than 10ppm does not indicate an absence of biomethane for all points in time.

The accuracy of the model only drops at the extreme of the penetration range of the biomethane. Here, it slightly under-estimates the reach, predicting that it will not get as far as FBM52 and FBM53, whereas in reality it has been shown to occasionally reach these points. These are the points that are furthest away from the source, which can be most clearly seen below in Figure 51.

The model is therefore highly accurate for the majority of the biomethane range, but is slightly conservative in predicting its reach. These results provide confidence that for the vast majority of the biomethane-affected area, results from the model accurately reflect reality in terms of the presence or absence of biomethane.

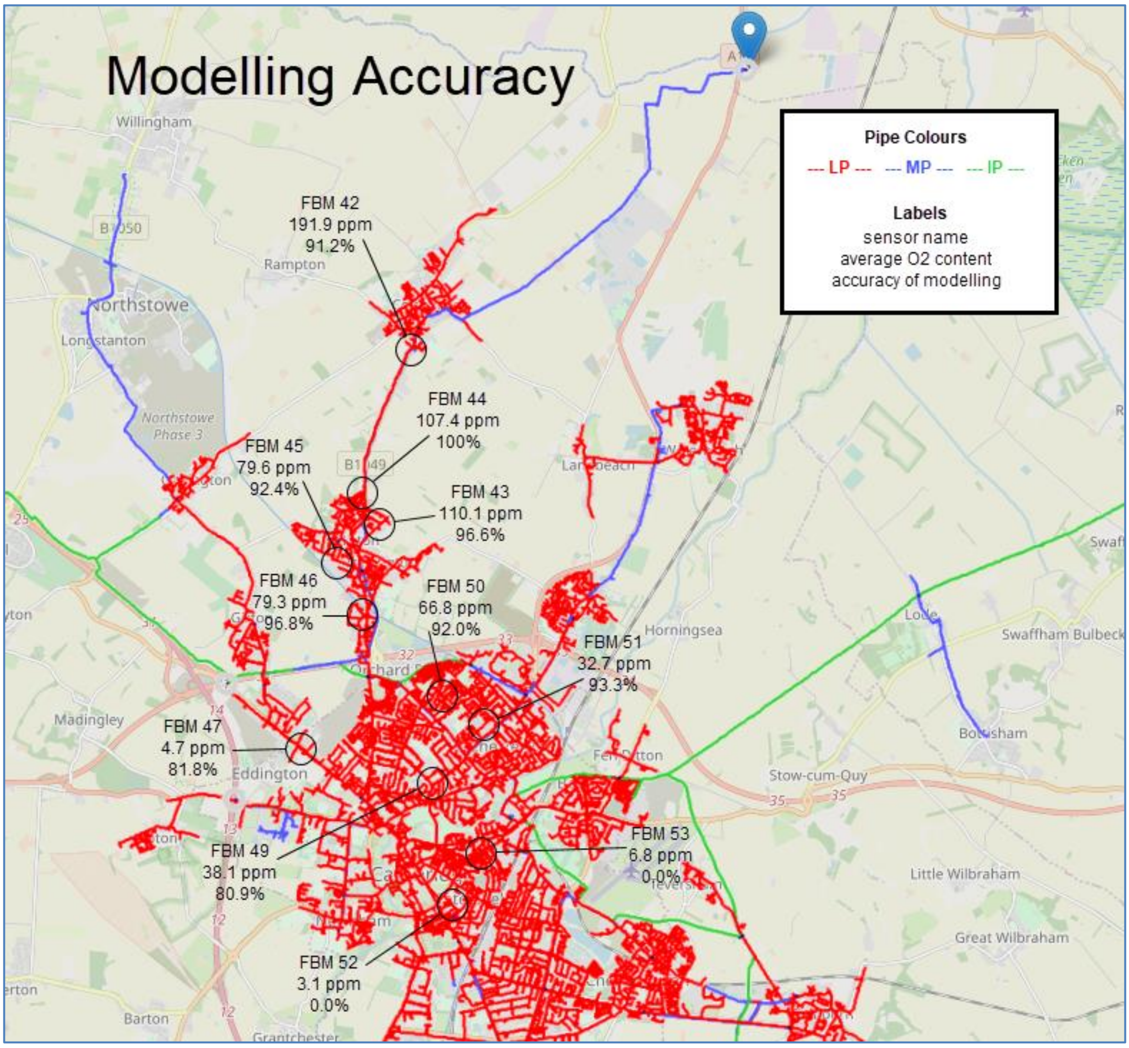

Figure 51 – Network Map of Model Accuracy for the Cambridge Network

6.5 Summary

Through the data visualisation (Section 4) the evidence is available to confirm that consumers do receive gas from different entry points into the network. With the principle of consumers receiving gas from different sources established, it is important to show that the network analysis model can be used to predict a biomethane-affected zone at the varying demand levels experienced and that a model could therefore be used as a basis for defining a suitable Charging Area.

This section has taken the measured oxygen data and compared it to the calculated results from the network analysis modelling. Network modelling seeks to predict the overall behaviour of the network with a generic consumer demand profile as there is no information on the actual consumer gas consumptions for the periods of analysis.

The network modelling has been shown to be highly accurate for the majority of the biomethane range, but is slightly conservative in predicting its reach. These results provide confidence that for the vast majority of the biomethane-affected area, results from the model accurately reflect reality in terms of the presence or absence of biomethane.

Through the screen captures of the network analysis models and the charts of the network modelling results, this section has demonstrated a strong correlation between the network modelling results and the FBM field trial oxygen measurements across the two field trial networks. The example network models are able to show the penetration of oxygen into the wider network and there is the expectation that the network modelling techniques applied to these trial models will work successfully on other gas distribution networks in GB.

7 MODELLING OXYGEN CONTENT AND CV OF THE GAS

7.1 Overview

The measured data from the oxygen sensors show that gas from the biomethane site travels through both the Cambridge and Lincolnshire networks and the distance travelled is linked to the level of network demand, biomethane flows and network dynamics. The understanding of flows and mixing of gases provided by the network analysis software enables the modelling of different CV input points across a gas network. The field trials have demonstrated that the bulk of the embedded biomethane gas supplies consumers local to the input point. Biomethane gas was measured across a wide area, though at low oxygen concentration levels this do not materially impact the CV received by a consumer.

The present LDZ FWACV regime limits the variation in CV for gas inputs within a maximum range of 1MJ/m3 across the relevant LDZ. For lower-CV sources such as biomethane, this standardisation of CV is achieved by enriching the biomethane with high-carbon propane prior to injection into the gas distribution network, to meet a specified CV target that is in line with the primary LDZ inputs from the NTS[11].

In order to be able to remove the requirement for enrichment of lower-CV gases such as biomethane and to gain the full carbon benefit of their use, it is necessary to attribute that lower-CV gas, as far as practicable, to those consumers who are supplied with it, by creating an embedded Charging Area within the LDZ. Otherwise, the CV cap would remain in constant operation, resulting in a very significant distortion in billing, or, if the CV cap were removed by a change to regulations, the application of uncapped FWACV would significantly disadvantage those consumers in receipt of the lower-CV gas.

The principles described above are also valid for higher-CV sources such as LNG where a standardised CV is achieved by ballasting the LNG with nitrogen to lower the delivered CV.

Section 6 has demonstrated that the network models can predict the variation in measured oxygen readings by modelling the mixing of gases in the network. The next step is to use these same models to show how CV varies through a network, depending upon the source input values and gas network system conditions.

Based on defined CV values at entry points, the models can be set up in a similar way to that undertaken in Section 6.1, and identify what CV could be expected at each consumer location at demands levels across the year.

7.2 Modelling the Current FWACV Position

Using the functionality within Synergi Gas, the model for the Cambridge network has been set up to represent the current CV entry values into the network; that is the NTS gas with a CV based on the average of 39.1 MJ/m^3 from NTS data[12] and propanated biomethane at Chittering of 38.9 MJ/m^3 from the Cadent Operational Data; a narrow range of CVs as required by the FWACV regime. This modelling is indicative of the current FWACV position, as shown in Figure 52.

[11] Where the biomethane input point can be located in a “demand-sterile” part of the network and mixing with gas already in the system can be guaranteed to achieve a “within-tolerance” CV upstream of the nearest demand, enrichment with propane may be avoided.

[12] National Grid UK Transmission - Data Finder and Explorer https://mip-prd-web.azurewebsites.net/DataItemExplorer/Index

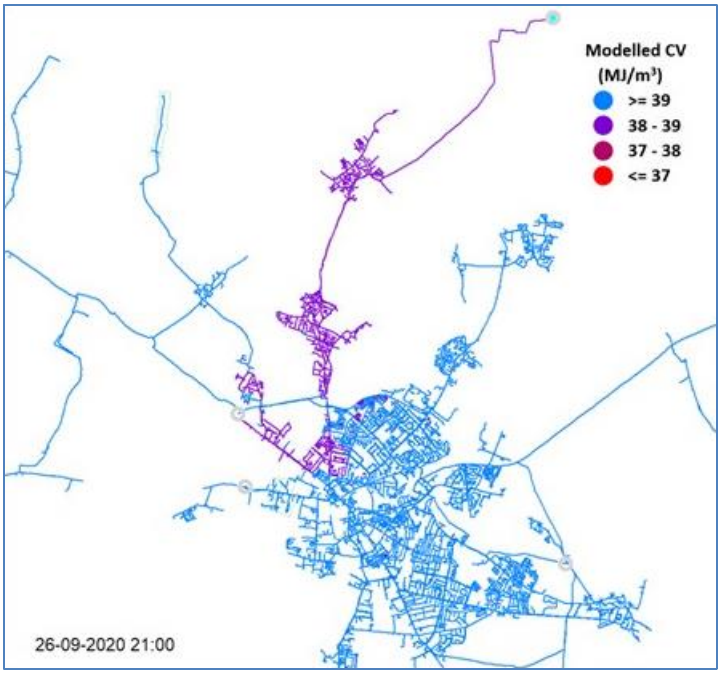

Figure 52 – Modelled CV 26th September 2020 21:00 Cambridge Network

The CV values calculated in the modelling are limited within the range of the CVs of the gas entering the network. Even with the small range of CV that is being modelled, the results show a distinct zone of influence of the lower CV gas.

Figure 53 shows a different modelled time period of 15:00 on 27th September 2020. These results also show a distinct zone of influence of the lower CV gas.

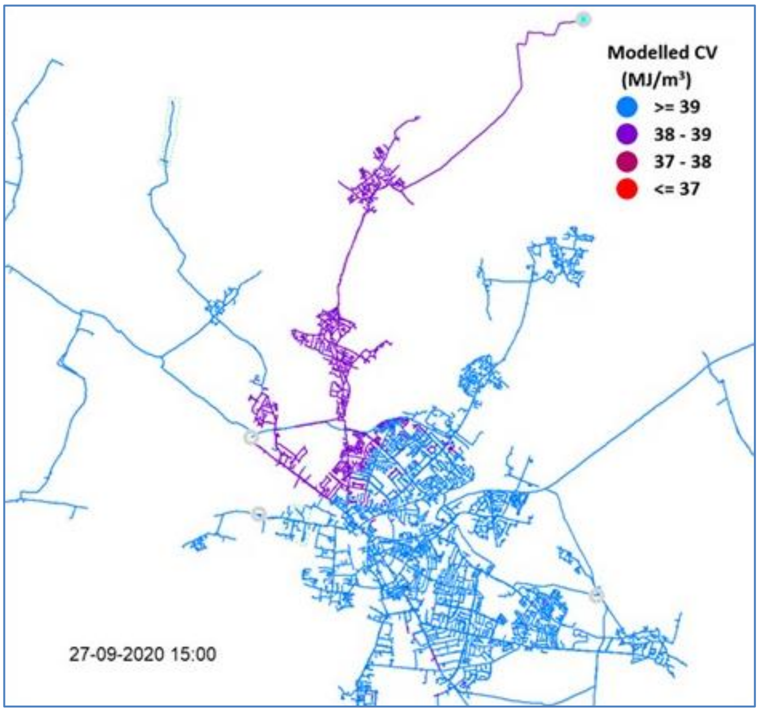

Figure 53 – Modelled CV 27th September 2020 15:00 Cambridge Network

Figure 54 shows a side by side comparison of the measured and modelled oxygen ppm readings for 15:00 on 27th September 2020, alongside the modelled CV for the same time period. As expected, the zones are comparable.

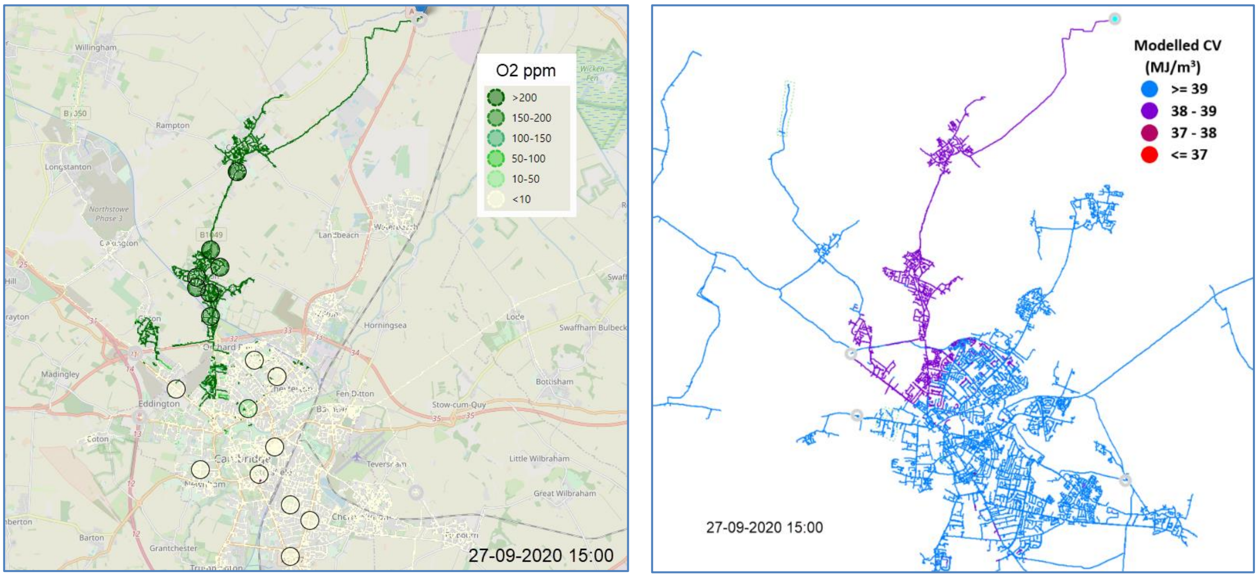

Figure 54 – Comparison Between Measured & Modelled Oxygen Values and Modelled CV 27th September 2020 15:00 Cambridge Network

Given that the network modelling provides an understanding of how the network performs over time, there is an alignment between the modelled pipes coloured up as receiving the lower CV gas (Figure 52 and Figure 53) and the measured and modelled oxygen ppm values shown in Section 6.2.

7.3 Modelling of Unpropanated Entry Gas

The next step in the modelling process is to consider the removal of the CV constraints from the current billing arrangements, i.e., any GSMR compliant gas is allowed to enter the gas network.

In the example of Chittering and Hibaldstow, this would mean removing the propanation of the biomethane to allowing the lower CV gas into the network.

Figure 55 and Figure 56 show Synergi Gas screenshots of the variation of CV across the Cambridge network. The unpropanated biomethane at Chittering, has an indicative CV of 37.0 MJ/m^3 and the NTS gas with an indicative CV of 39.1 MJ/m^3.

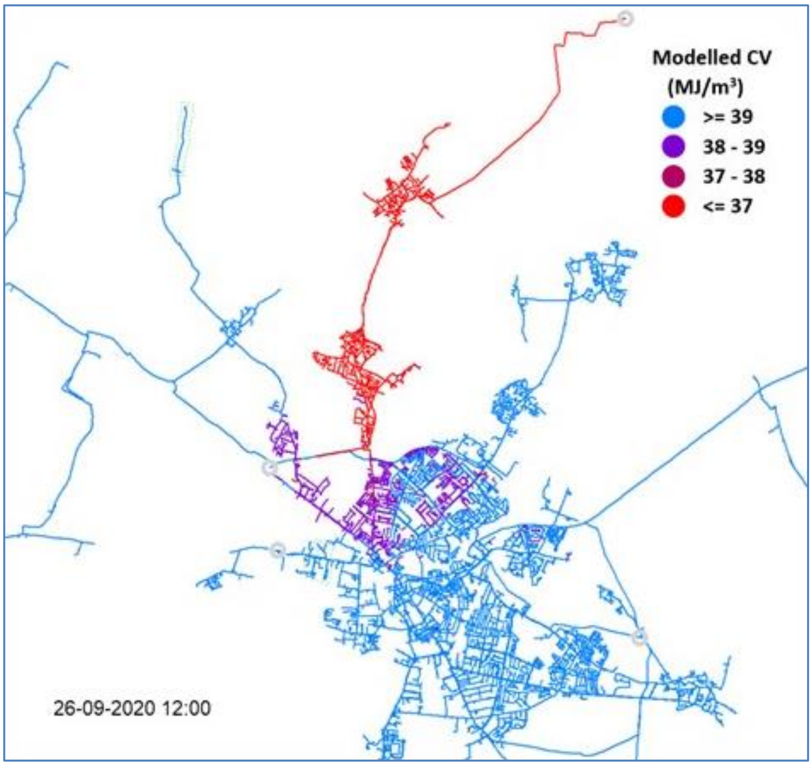

Figure 55 – Modelled CV 26th September 12:00 Cambridge Network

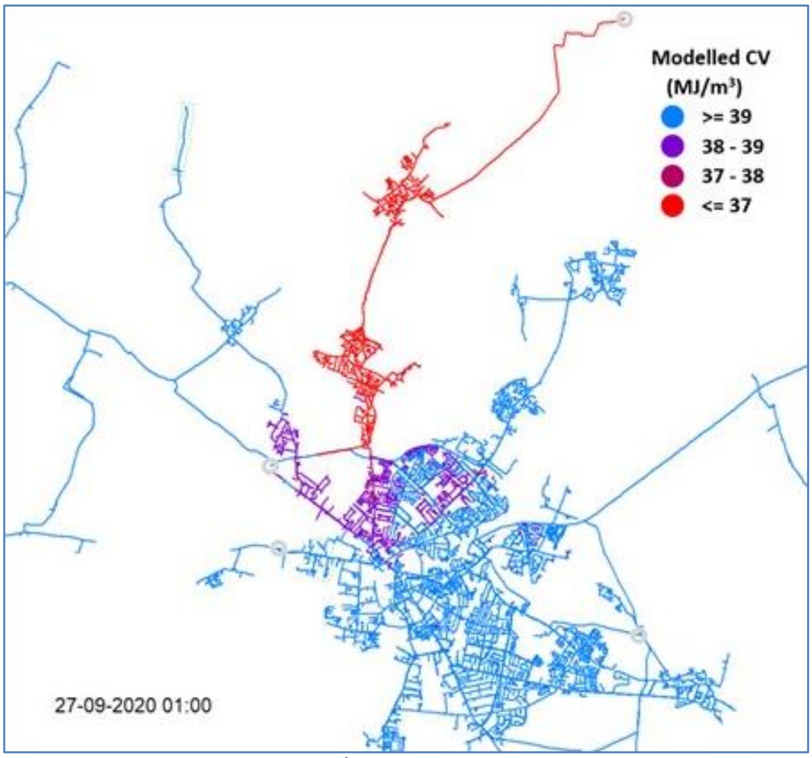

Figure 56 – Modelled CV 27th September 01:00 Cambridge Network

The results show the distinct zone of low CV gas from Chittering, pipes coloured in red. As this gas travels further into the network it mixes with the higher CV NTS gas. The low CV biomethane gas from Chittering has a minimal impact on the general network CV due to this mixing.

When gases of different oxygen content and CV mix, the resulting CV is based upon the mixing ratio and the input CV values. As an example of, Figure 57 shows the impact of introducing unpropanated gas at Chittering with a CV of 37 MJ/m^3. The figure indicates the likely CV given the oxygen content. For example, an oxygen read of 2000 ppm would correspond to a CV of 37 MJ/m^3 and an oxygen read of 200 ppm would correspond to a CV of 38.9 MJ/m^3.

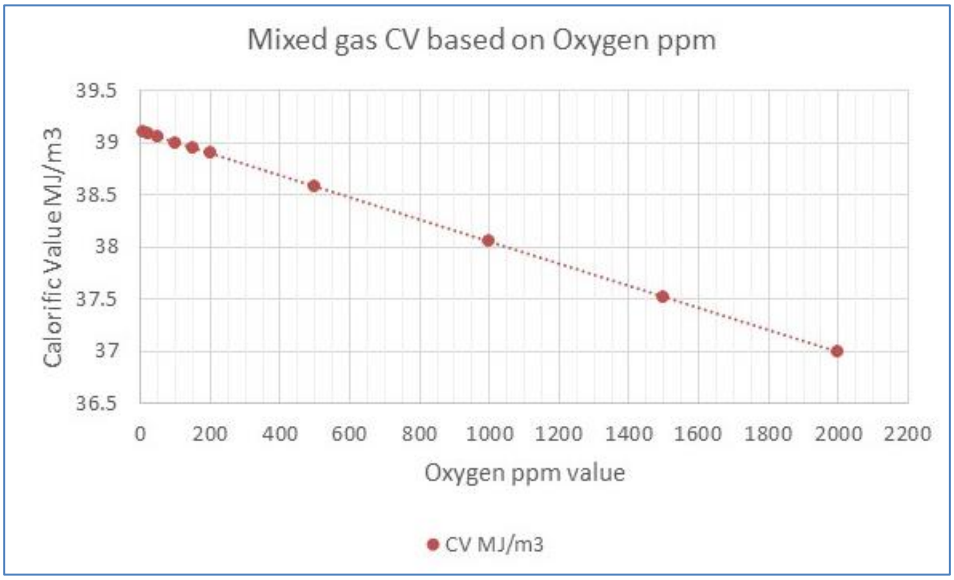

Figure 57 – Example CV to Oxygen ppm Ratios

7.4 Modelling of hydrogen blend gas entry on higher pressure tiers

Since the FBM NIC submission in 2016, there has been significant developments in the potential use of hydrogen and hydrogen blend into the gas network as part of the decarbonised pathway. This section shows that using Falcon network analysis software the travel and mixing of gases of different CV can be modelled. The example below models a hydrogen blend gas with a CV of approximately 34 MJ/m^3, which is significantly different to the prevailing CV of the natural gas fed into the network from the NTS. In addition, the section of the network modelled also includes two smaller volume embedded biomethane inputs.

The network analysis model, provided by Cadent, has been set up using the following parameters:

- Day 46 (high demand)
- Natural gas assumed CV of 39 MJ/m3
- Hydrogen-blend site assumed to deliver a resultant CV of 34 MJ/m3 which reflects an approximately 20% blend ratio with the natural gas
- Biomethane injection points have a CV of 37 MJ/m3
- Assumed profiles of gas supplied from the NTS supporting LTS linepack for the DN

The images below (Figure 58) are a sequence of screenshots from Falcon. The pipes are coloured by CV, blue being the lower end of the range and red the upper end. There are two main feeds into this section of the model, a natural gas infeed at WARB (39 MJ/m^3) and the hydrogen blend infeed at PART (34 MJ/m^3), along with smaller biomethane injections at BGDAVE and BGBRED (37 MJ/m^3). The lower CV gas from PART is immediately blended with gas from WARB, giving a range of CVs from 36.25 to 37.75 MJ/m^3 over the day at PARB depending upon the assumed flow rate profiles at these two entry points.

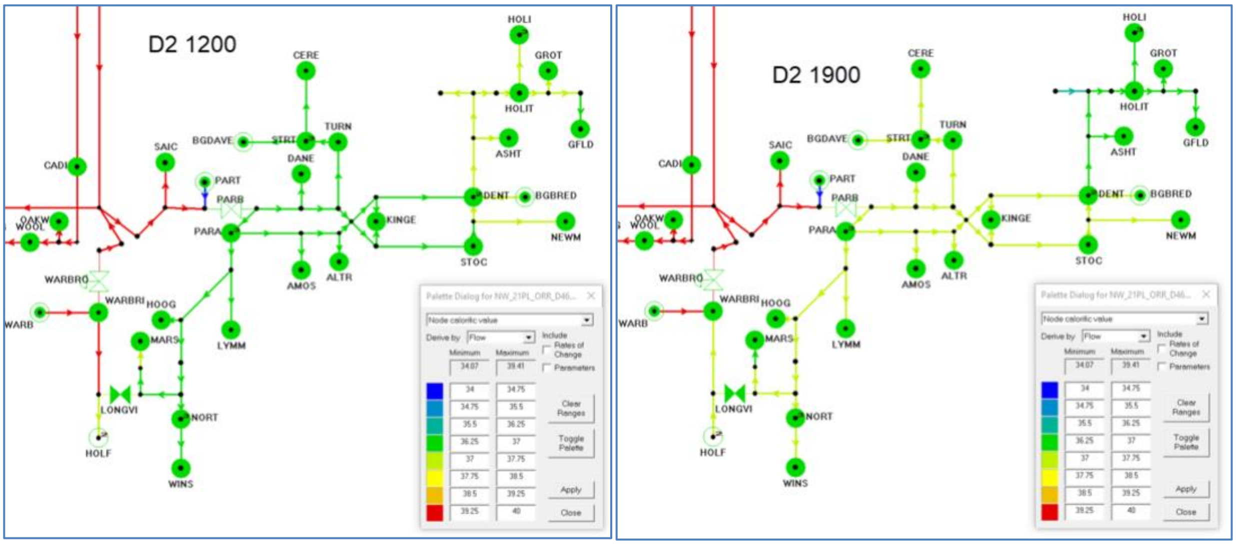

Figure 58 – Falcon CV Modelling of Hydrogen Blend

This section of the network supplied by gas originating from PART sees average gas CVs of around 37 MJ/m^3. However, there are times when the modelling shows lower CV gas downstream of the valve PARB. The following table gives the range in modelled CVs at three selected network nodes over a 24 hour period:

Site	Max CV (MJ/m^3)	Min CV (MJ/m^3)	Average CV (MJ/m^3)
AMOS	38.88	35.75	37.02
KINGE	37.76	36.45	36.93
GROT	37.76	36.26	37.0

Table 6 – CV Ranges for Selected Nodes from Falcon

These selected nodes in the network analysis model indicate that despite the range in CV, over a 24 hour period the average hourly CV is similar.

The results show that it is possible to use network analysis software to model the travel and mixing of gas on higher pressure tiers and for larger volumes such as hydrogen blend. For the given input parameters and network configuration it is possible to identify zones with gas of a different CV.

7.5 Summary

These images show that the network analysis software can be used to model gases from sources of differing CVs. CV modelling can indicate the range of CVs across a network for different supply and demand conditions. The functionality within Synergi Gas, Falcon and GBNA[13] network analysis software would also be suitable for use in the definition of a CV Charging Area.

[13] Additional CV tracking functionality to provide CV results to the user is on the GBNA development roadmap.

8 PROJECT OPTIONS FOR DEFINING A CHARGING AREA

8.1 Overview

This report has illustrated:

- the principle of consumers receiving gas from different sources,
- that network modelling can be used to predict the zones of different CVs, comparable to the lower CV biomethane-affected zone at different demand levels,
- the network model could therefore be used as a basis for defining a suitable Charging Area.

This section explores four options for a future billing methodology, and draws on learning from discussions with gas transporters and Xoserve.

An initial cost benefit analysis of the three options was completed for the Ofgem Project Progress Report, December 2017; https://futurebillingmethodology.co.uk/wp-content/uploads/2017/12/FBM-Project-Progress-Report-Final-v2.pdf.

Based on the confirmation that the network models can be used to evaluate the variation in gas CV across a network and demonstration of how in the field trials the "affected zone" varies with demand, it has been possible to demonstrate the impact of removing the propane at a biomethane entry point. The techniques adopted for this analysis would also apply to assessment of high CV LNG and future hydrogen / natural gas blending entry points.

It was recognised at the start of the project, and highlighted in the early industry consultation in 2017, that the size of the zone around a biomethane entry point would vary depending on entry flow and the local demand. The entry flow for a biomethane plant is generally constant over a year and as such at times of lower demand the gas reaches consumers further into the network than at higher demand when the gas is consumed closer to the entry point.

The focus for FBM modelling has been to develop a Charging Area methodology that is:

- straightforward to define,
- simple to implement,
- and equitable to consumers on the network.

Currently the Charging Area is an LDZ, a geographically defined area with identifiable entry points for gas, each of which has fiscal flow measurement and an associated gas quality measurement device.

Starting simply, in Figure 59 below, with 'A' a natural gas input and 'B' a low CV input, the CV at node 'C' will vary with the volumes and CV of the gases at A and B and the Charging Area for B will increase as its percentage volume of the total input increases.

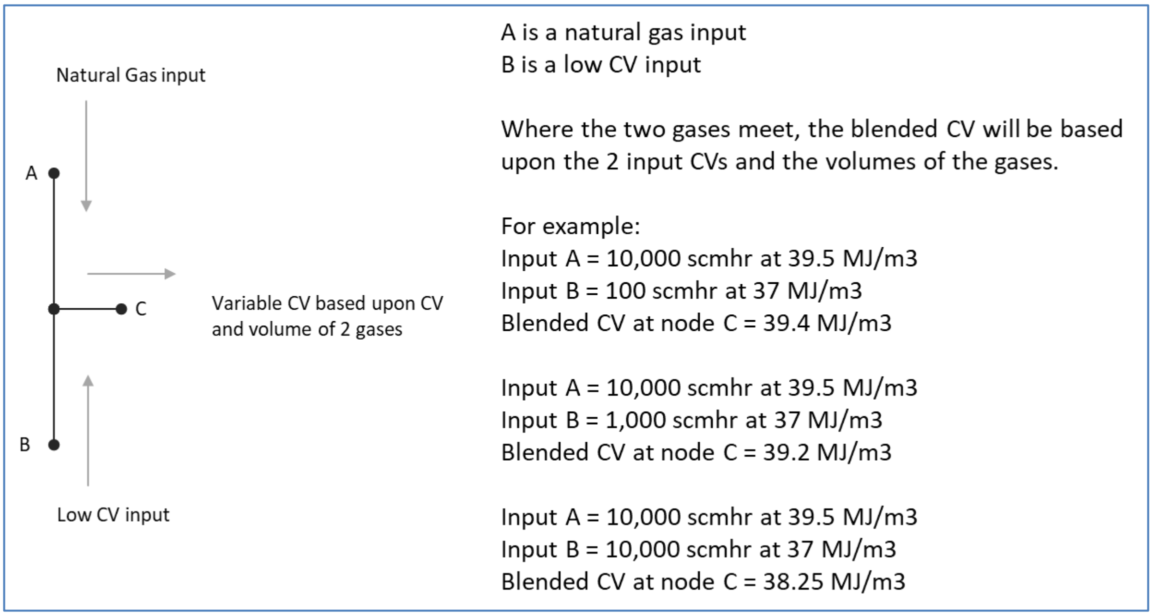

Figure 59 – Simple Example of Different CV Input Values

There will be variation in the input volumes of the different gases and demand over a period of time resulting in a moving boundary of the low CV gas. The CV at nodes within the network will vary and an appropriate Charging Area is required for equitable billing to the consumer.

The following subsections identify, at a conceptual level, possible methods for defining Charging Areas for further exploration including industry consultation. Fundamental to each option is that all SMPs are allocated an individual billing CV. SMPs may be grouped together and assigned to the same CVDD or modelled CV, but there is an underlying assumption that billing CVs are assigned at SMP level. In addition, it has been assumed that any amendments required to Xoserve and Shipper billing systems will be the same regardless of the method used to define the Charging Area.

The first three methods detailed below align to the original NIC options and the fourth method has evolved with the project. In summary:

- Options 1 and 2 require network modelling to define the Charging Area and assign a consumer to that Charging Area
- Option 3 requires limited network modelling to determine the most appropriate position of the within network CV measurement
- Options 1, 2 and 3 use measured CVs for consumer billing
- Option 4 uses measured CVs as an input for network modelling which generates a modelled CV for consumer billing.

The methods have been sub-divided into two groups, one where there is the requirement for a CVDD for billing purposes and the second where a modelled CV can be used for billing purposes.

Section 9 covers in more detail a number of modelling and operational factors that need to be considered when undertaking the network analysis associated with defining a Charging Area.

8.2 Measured CVs used for Consumer Billing

Through the network modelling work a number of approaches have been explored to allocate SMPs to a specific Charging Area. The identification of a Charging Area through annual gas use analysis was deemed the most equitable

Pragmatic approach and as such is presented below. Further description including the pros and cons of alternative approaches to the Pragmatic Option described below are detailed in Appendix D.

8.2.1 Option 1 Pragmatic - Identify Charging Areas through Annual Use Analysis

The Pragmatic Option facilitates transportation of gases having a marked difference in CV to the prevailing network/LDZ CV, although still within the GS(M)R limits, into the network, typically from an embedded entry point, without the need to increase CV by use of propane (or reducing CV by ballasting with nitrogen) in order for the entry gas to remain within the current FWACV limits.

The original aim of the Pragmatic Charging Area was that it could be:

- simple to define and remain fixed with consumers allocated to an entry point or FWACV until significant changes in the network or biomethane entry flow is noted,
- simpler to implement within existing billing systems compared with the Composite Option,
- equitable to consumers in the different Charging Areas,
- based on modelling without the reliance on additional within-network measurements.

This approach would identify the zone of influence from any embedded gas inputs to the LDZ and separate this from the rest of the LDZ network. In simple terms, in an LDZ with one embedded biomethane input point and four NTS input points, there would be two Charging Areas under the Gas (Calculation of Thermal Energy) Regulations: one for the biomethane zone and another for the remainder of the LDZ.

It is proposed that this method uses network CV modelling and consumer annual use profiles to generate a financial "typical consumer bill" analysis. All SMPs within an identified low-CV Charging Area would be assigned to the low-CV CVDD, while all others would be assigned to the LDZ FWACV. While the worked example below has focused on a typical domestic consumer, it has also been developed to look at the financial implications on non-domestic consumers. This method can be equally applied to a high-CV embedded entry and is summarised below in Figure 60.

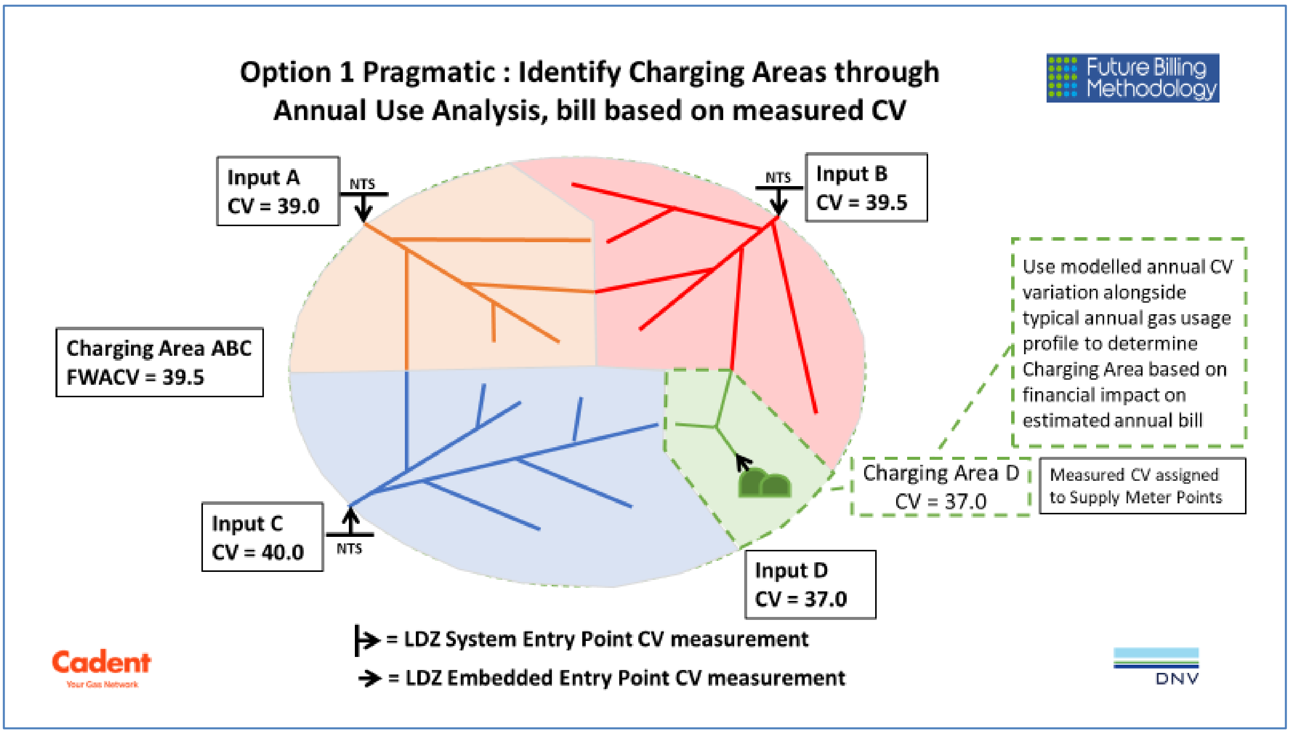

Figure 60 Option 1 Pragmatic - Identify Charging Areas through Annual Use Analysis

Using the network analysis model, including demand variation and operational settings, a CV profile at nodes across the network can be generated. This predicted CV variation across the year can be used to generate a financial bill impact analysis at each node to understand the impact of that node being assigned to an embedded entry node or FWACV, therefore determining a Charging Area for an embedded entry. This enables a rational approach to billing with the inclusion of embedded entry gases which are of a higher or lower CV compared to the prevailing CV. The time steps chosen to create the CV profiles would need to be determined / agreed, for example 365 days, monthly, quarterly.

Modelling of the CV across the year could be an automated approach, including variations in demand, to generate the CV profile and financial bill impact. This upfront allocation to a Charging Area would be a simpler approach than recreating an ‘after the day’ model on a daily basis, even if automated. Within the MS13 network analysis, the processes followed have highlighted the difficulties in trying to replicate the localised within day demands and flows at a low pressure level without additional data availability.

8.2.1.1 Worked Example

With network energy modelling able to predict the variation in CV across a network and therefore the modelled CV of the gas delivered to individual consumers, the next step is to understand what impact a more specific CV Charging Area would have on a consumer’s gas bill.

The gas meters used in the UK measure gas by volume. The volume of gas passed through a consumer’s meter is based upon their energy requirement (i.e., gas appliances) at the CV of the gas delivered at their meter.

For a consumer’s gas bill, their metered volume of gas is combined with the daily LDZ FWACV for the billing period to generate the consumer’s gas bill. So, even under the current FWACV regime, the consumer’s gas bill does not reflect the actual CV of gas delivered at their meter.

Current FWACV Billing Methodology

In presenting the information about the impact CV can have on a gas bill, an understanding of a typical energy use profile and the CV received by a consumer is required.

Figure 61 shows an indicative daily energy use profile for a typical domestic consumer over a year (13,600 kWh) and an indicative annual CV profile for selected sensor locations within Cambridge.

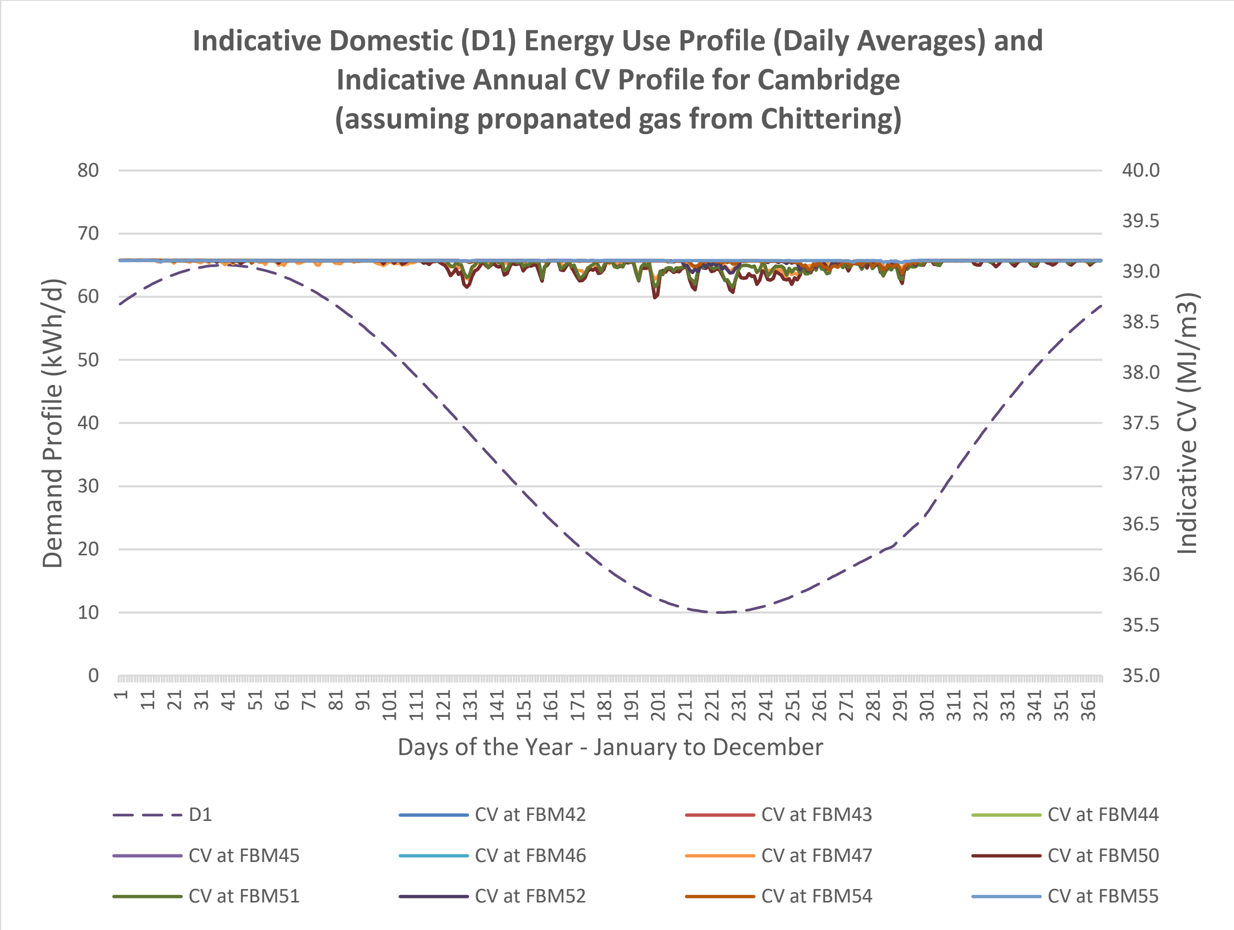

Figure 61 – Indicative Daily Gas Energy Use Profile for a Typical Domestic Consumer (D1) and Indicative CV Profile for Cambridge (Assuming Propanated Gas from Chittering)

From the graph it can be seen that there is little variation in the CV received at the individual FBM sensor locations. Currently for Cambridge, the CV received by a consumer would be between the local “NTS” CV value (estimated at 39.1 MJ/m^3) and Chittering propanated biomethane CV (estimated at 38.8 MJ/m^3) depending on location and mixing of gas within the network.

The first part of the worked example below assumes this relatively homogeneous CV profile and annual energy use.

	A1	B1	C1	D1	E1	F1	G1	H
	Days CV>39 MJ/m³	Days 37.1<CV< 39 MJ/m³	Days CV<37.1 MJ/m³	Metered Volume m³	Average CV MJ/m³	Max CV MJ/m³	Min CV MJ/m³	Energy Actual Cost
FBM42	299	67	0	1281.15	39.1	39.1	38.7	£610.56
FBM43	299	67	0	1281.15	39.1	39.1	38.7	£610.56
FBM44	329	37	0	1280.80	39.1	39.1	38.8	£610.56
FBM45	362	4	0	1280.38	39.1	39.1	39.0	£610.56
FBM46	365	1	0	1280.36	39.1	39.1	39.0	£610.56
FBM47	347	19	0	1280.84	39.1	39.1	38.9	£610.56
FBM50	299	67	0	1281.15	39.1	39.1	38.7	£610.56
FBM51	329	37	0	1280.80	39.1	39.1	38.8	£610.56
FBM52	362	4	0	1280.38	39.1	39.1	39.0	£610.56
FBM54	365	1	0	1280.36	39.1	39.1	39.0	£610.56
FBM55	366	0	0	1280.24	39.1	39.1	39.1	£610.56

Table 7 – Current FWACV Modelled Example Part 1

In Table 7 columns A1 to C1 show the number of days within a year that a range of modelled CVs are received at the selected FBM sensor locations. Using the data from Figure 61 (CV and energy use) the metered flow for each day can be determined and the total annual metered volume is shown in column D1. There is a limited range of CVs, but comparing the metered volume at FBM55 which always receives the highest CV, with the other FBM locations, FBM55 location has a slightly lower metered volume. Columns E1, F1 and G1 show the range of CVs received.

The final column, H, is the Energy Actual Cost for a typical consumer at each location, based on a standard gas price and the CV profile specific to that individual location. As each consumer has the same annual gas energy requirement, and the cost is calculated based on the 'actual' CV of gas received at each location, the "Energy Actual Cost" is the same for consumers at each location (i.e., higher CV = lower metered volume). So, the Energy Actual Cost represents what the consumer should be billed if energy attribution to metered gas flows was perfect.

	D1	H	I1	J1
	Metered Volume m³	Energy Actual Cost	Billed on FWACV 38.6 MJ/m³	Billed on FWACV 39.5 MJ/m³
FBM42	1281.15	£610.56	£603.05	£617.11
FBM43	1281.15	£610.56	£603.05	£617.11
FBM44	1280.80	£610.56	£602.88	£616.94
FBM45	1280.38	£610.56	£602.68	£616.73
FBM46	1280.36	£610.56	£602.67	£616.72
FBM47	1280.84	£610.56	£602.90	£616.96
FBM50	1281.15	£610.56	£603.05	£617.11
FBM51	1280.80	£610.56	£602.88	£616.94
FBM52	1280.38	£610.56	£602.68	£616.73
FBM54	1280.36	£610.56	£602.67	£616.72
FBM55	1280.24	£610.56	£602.62	£616.67

Table 8 – Current FWACV Modelled Example Part 2

In Table 8, columns I1 and J1 use the metered volume (column D1) of gas combined with a daily FWACV for the billing period to generate the consumer's gas bill. For simplicity, column I1 has assumed a single daily FWACV of 38.6 MJ/m³ and column J1 has assumed a single daily FWACV of 39.5 MJ/m^3; two different LDZ FWACVs above and below the local input CV. The values in column I1 illustrate the impact of billing with a CV less than the received CV; a cost lower than the energy cost (column H). The values in column J1 illustrate the impact of billing with a CV higher than the received CV; a cost higher than the energy cost (column H).

The principles and effects outlined in the tables above are those which apply under the current FWACV billing mechanism. Consumers that receive gas with a CV lower than the FWACV are being slightly overcharged while those receiving gas with a CV higher than the FWACV are being slightly undercharged: thus cross-subsidy between consumers exists under today's billing regime.

Future Charging Area / Zone Identification Scenarios

If the industry were to integrate diverse gas sources without standardising the energy content, the present homogenised CV profile would be replaced with a more variable CV profile. Allowing un-propanated biomethane at Chittering into the network would create such a profile. Figure 62 shows an indicative daily energy use profile for a typical domestic consumer over a year (13,600 kWh), the same data as shown in Figure 61, and an indicative annual CV profile for selected sensor locations within Cambridge, different data to that shown in Figure 61.

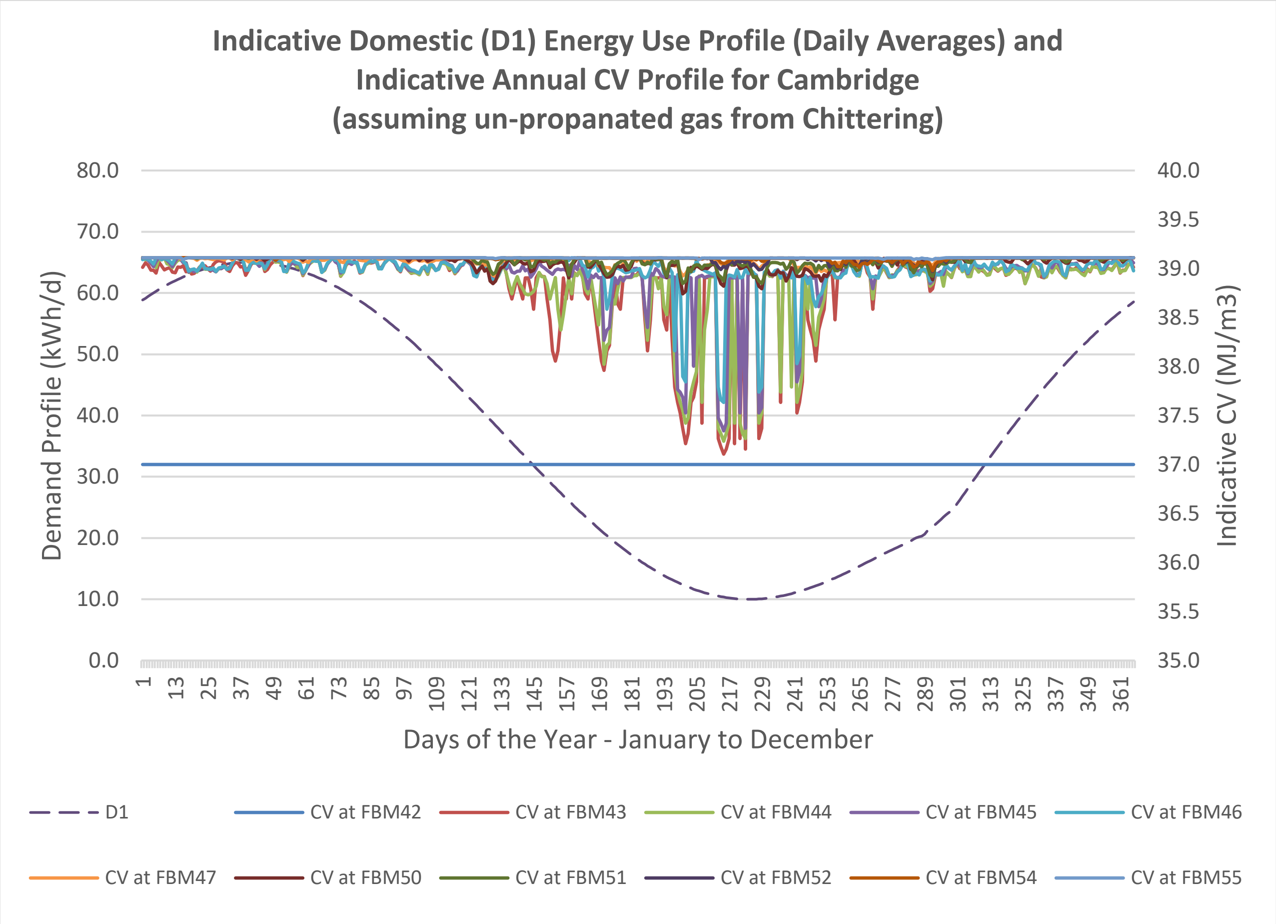

Figure 62 – Indicative Daily Gas Energy Use Profile for a Typical Domestic Consumer (D1) and Indicative CV Profile for Cambridge (Assuming Unpropanated Gas from Chittering)

From the graph it can be seen that there is variation in the CV received at the individual FBM sensor locations. In this example, the CV received by a consumer would be between the local "NTS" CV value (estimated at 39.1 MJ/m^3) and Chittering un-propanated biomethane CV (estimated at 37.0 MJ/m^3) depending on location and mixing of gas within the network. In this example, the CV at the majority of locations remains steady until the summer months which coincides with the reduction in energy use of a consumer.

The second part of the worked example below assumes this variable modelled CV profile, but the typical annual energy use profile remains unchanged at 13,600 kWh.

	A2	B2	C2	D2	E2	F2	G2	H
	Days CV>39 MJ/m^3	Days 37.1<CV<39 MJ/m^3	Days CV<37.1 MJ/m^3	Metered Volume m^3	Average CV MJ/m^3	Max CV MJ/m^3	Min CV MJ/m^3	Energy Actual Cost
FBM42	0	0	366	1353.20	37.0	37.0	37.0	£610.56
FBM43	111	255	0	1286.07	38.8	39.1	37.1	£610.56
FBM44	121	245	0	1285.58	38.8	39.1	37.2	£610.56
FBM45	165	201	0	1284.03	38.9	39.1	37.3	£610.56
FBM46	198	168	0	1283.25	39.0	39.1	37.6	£610.56
FBM47	347	19	0	1280.84	39.1	39.1	38.9	£610.56
FBM50	299	67	0	1281.15	39.1	39.1	38.7	£610.56
FBM51	329	37	0	1280.80	39.1	39.1	38.8	£610.56
FBM52	362	4	0	1280.38	39.1	39.1	39.0	£610.56
FBM54	365	1	0	1280.36	39.1	39.1	39.0	£610.56
FBM55	366	0	0	1280.24	39.1	39.1	39.1	£610.56

Table 9 – Future Variable CV Modelled Example Part 1

Figure 62 and columns A2, B2 and C2 (Table 9) provide an example of the output from the conversion of the measured oxygen values in Cambridge to a CV value. This has been based on the mixing ratio of the 2000 ppm biomethane with the ~10 ppm NTS gas to get the derived value. These oxygen levels do not cause a large change from the NTS CV at this concentration. An oxygen reading at 200ppm is a ratio of Biomethane to NTS flow of 1:9 giving a combined CV of 38.9MJ/m3 close to the NTS CV value. In addition, for the oxygen recordings above the 200 ppm sensor limit, network modelling has been used to infer the CV. If this principle of CV profiling across a network were to be explored in further detail or implemented for Charging Area identification, thermal CV network modelling should be undertaken.

Using the data from Figure 62 (CV and energy use) the metered flow for each day can be determined and the total annual metered volume is shown in column D2. The wider range of CVs results in more variable metered volumes of gas required for the same energy requirement. The locations with a lower CV require a larger volume of gas compared to the locations of higher CV; most noticeable when comparing FBM41 and FBM55. Columns E2, F2 and G2 show the range of CVs received.

The final column, H, is the Energy Actual Cost for a consumer at each location based on a standard gas price and the location-specific CV profile. As before, each consumer has the same energy use profile, and the cost is calculated based on the actual received CV, the “Energy Actual Cost” is the same for every location.

As with the current billing mechanism, consumers will be allocated to a Charging Area with a billing CV. Moving to a more specific CV Charging Area, in this example, there are options for the billing CV shown in Table 10 columns I2, J2, and K.

	D2	H	I2	J2	K
	Metered Volume m^3	Energy Actual Cost	Billed on FWACV 38.6 MJ/m^3	Billed on FWACV 39.5 MJ/m^3	Billed on 37 MJ/m^3
FBM42	1353.20	£610.56	£636.96	£651.81	£610.56
FBM43	1286.07	£610.56	£605.36	£619.48	£580.27
FBM44	1285.58	£610.56	£605.13	£619.24	£580.05
FBM45	1284.03	£610.56	£604.40	£618.49	£579.35
FBM46	1283.25	£610.56	£604.03	£618.12	£578.99
FBM47	1280.84	£610.56	£602.90	£616.96	£577.91
FBM50	1281.15	£610.56	£603.05	£617.11	£578.05
FBM51	1280.80	£610.56	£602.88	£616.94	£577.89
FBM52	1280.38	£610.56	£602.68	£616.73	£577.70
FBM54	1280.36	£610.56	£602.67	£616.72	£577.69
FBM55	1280.24	£610.56	£602.62	£616.67	£577.64

Table 10 – Future Variable CV Modelled Example Part 2

Moving to a more specific CV Charging Area, in this example, the billed CV will be either the biomethane value or a FWACV value depending on which Charging Area a consumer is allocated to.

Columns I2, J2 and K (Table 10) use the metered volume of gas (column D2) combined with a daily FWACV for the billing period to generate the consumer's gas bill. For simplicity, a single daily value has been used; I2 a FWACV of 38.6 MJ/m^3, J2 a FWACV of 39.5 MJ/m^3 and K a local CV of 38.8 MJ/m^3. Column K applies the same calculation but uses the low CV entry as the billing CV.

The variation in the bills are a consequence of the increased differences in metered volume to deliver the same energy requirement, so exacerbating differences between the energy actually taken and the energy billed for, with a consequential under/over payment against the "Energy Actual Cost". Consumers that receive gas with a CV lower than their billing CV are further overcharged while those receiving gas with a CV higher than their billing CV are being undercharged: extending the cross-subsidy between consumers. These differences are displayed in Table 11 and Table 12.

	H	Current LDZ FWACV Billing Mechanism					
		I1			J1		
		Billed on FWACV 38.6			Billed on FWACV 39.5		
	Energy Actual Cost	Bill	Price difference	% difference	Bill	Price difference	% difference
FBM42	£610.56	£603.05	-£7.51	-1.2%	£617.11	£6.55	1.1%
FBM43	£610.56	£603.05	-£7.51	-1.2%	£617.11	£6.55	1.1%
FBM44	£610.56	£602.88	-£7.68	-1.3%	£616.94	£6.38	1.0%
FBM45	£610.56	£602.68	-£7.88	-1.3%	£616.73	£6.18	1.0%
FBM46	£610.56	£602.67	-£7.89	-1.3%	£616.72	£6.17	1.0%
FBM47	£610.56	£602.90	-£7.66	-1.3%	£616.96	£6.40	1.0%
FBM50	£610.56	£603.05	-£7.51	-1.2%	£617.11	£6.55	1.1%
FBM51	£610.56	£602.88	-£7.68	-1.3%	£616.94	£6.38	1.0%
FBM52	£610.56	£602.68	-£7.88	-1.3%	£616.73	£6.18	1.0%
FBM54	£610.56	£602.67	-£7.89	-1.3%	£616.72	£6.17	1.0%
FBM55	£610.56	£602.62	-£7.94	-1.3%	£616.67	£6.11	1.0%

Table 11 – Current FWACV Modelled Example Part 3

	H	Future Billing - SMP allocated to Entry Point Charging Area								
		I2			J2			K		
		Billed on FWACV 38.6			Billed on FWACV 39.5			Billed on 37		
	Energy Actual Cost	Bill	Price diff.	% diff.	Bill	Price diff.	% diff.	Bill	Price diff.	% diff.
FBM42	£610.56	£636.96	£26.40	4.1%	£651.81	£41.25	6.3%	£610.56	£0.00	0.0%
FBM43	£610.56	£605.36	-£5.20	-0.9%	£619.48	£8.92	1.4%	£580.27	-£30.29	-5.2%
FBM44	£610.56	£605.13	-£5.43	-0.9%	£619.24	£8.68	1.4%	£580.05	-£30.51	-5.3%
FBM45	£610.56	£604.40	-£6.16	-1.0%	£618.49	£7.93	1.3%	£579.35	-£31.21	-5.4%
FBM46	£610.56	£604.03	-£6.52	-1.1%	£618.12	£7.56	1.2%	£578.99	-£31.56	-5.5%
FBM47	£610.56	£602.90	-£7.66	-1.3%	£616.96	£6.40	1.0%	£577.91	-£32.65	-5.6%
FBM50	£610.56	£603.05	-£7.51	-1.2%	£617.11	£6.55	1.1%	£578.05	-£32.51	-5.6%
FBM51	£610.56	£602.88	-£7.68	-1.3%	£616.94	£6.38	1.0%	£577.89	-£32.67	-5.7%
FBM52	£610.56	£602.68	-£7.88	-1.3%	£616.73	£6.18	1.0%	£577.70	-£32.86	-5.7%
FBM54	£610.56	£602.67	-£7.89	-1.3%	£616.72	£6.17	1.0%	£577.69	-£32.87	-5.7%
FBM55	£610.56	£602.62	-£7.94	-1.3%	£616.67	£6.11	1.0%	£577.64	-£32.92	-5.7%

Table 12 – Future Variable CV Modelled Example Part 3

Table 11 and Table 12 provide a comparison of a consumers bills between the current FWACV billing and future billing CVs. The impact of the diverse received CV profiles and attribution to a billing CV can be seen by values in the 'Diff' columns; the difference between the 'bill' and the Energy Actual Cost.

In this example with a wider range of CV, it is only a consumer at location FBM42 that is significantly affected by which billing CV they are assigned to. Looking back at Figure 62, this is a direct consequence of always receiving the low CV gas. While other locations see a drop in the CV of the gas received, this is at a time when the energy use profile is low therefore having minimal impact on the metered volume.

While the worked example has focused on a typical domestic consumer, it has also been developed to look at the financial implications on non-domestic consumers. Using an 'average' AQ for different basic demand tags a profile of their gas use across the year has been generated, including a flat profile representing a continuous process load. The financial analysis indicates a similar price differential across all types of demand tags as that of the domestic consumer.

The key component to the financial impact analysis is the CV of the gas received. From Table 9, it can be seen that even though FBM43-46 see a minimum CV of 37 MJ/m^3 or just above, their modelled average values are much closer to the maximum CV. The biomethane gas has a minimal impact on the wider network CV; the modelling suggests that the network has a significant mixing of the biomethane with the natural gas.

The principles outlined in the tables above form the basis for determining an appropriate Charging Area; assigning consumers to a billing CV more aligned with their received CV: thus, reducing the potential in-equitability and cross-subsidy between consumers.

8.2.1.2 Summary

This high-level CV profiling and annual use analysis shows the minimal impact a low CV gas has on the received CV within the Cambridge network. The oxygen readings from the Cambridge network show that although the oxygen levels within the network are above the maximum NTS level of 10ppm for a considerable part of the city and for a period of the year, these oxygen levels do not cause a large change from the NTS CV at this concentration. In this example, if the biomethane were unpropanated at 37MJ/m^3, an oxygen reading at 200ppm is a ratio of Biomethane to NTS flow of 1:9 giving a combined CV of 38.9MJ/m^3 close to the NTS CV value.

In the example of Cambridge with unpropanated gas at Chittering, the Charging Area options could be:

a. Small Charging Area based on the area that only ever receives low CV gas – e.g., FBM42

b. A Charging Area based on the area that sees a variation in CV, including the low CV gas for a given time period, for example 6 months – e.g., including sites FBM42, FBM43, FBM44, FBM45 and FBM46

c. Large Charging Area boundary based on the area that sees a full range of CV i.e., the low CV gas even for one day in the year – e.g., all but FBM55.

In this example, based on the impact on the consumers bill, the most equitable arrangement across all consumers would appear to be achieved by setting the embedded zone boundary around the local area closest to the biomethane entry point; as this would theoretically minimise cross-subsidy between consumers. In Table 12, a consumer at FBM42 would be paying disproportionately more than at all other locations, unless they were billed on the CV of 37 MJ/m^3 i.e., that measured at the biomethane entry point.

Appendix D.1 Pragmatic Option - Identify Different-CV Charging Area using CV Modelling provides worked example of alternative approaches to defining a Charging Area under the Pragmatic Option. These include defining Charging Area based on:

- Analyses at different levels of demand
- Variations in CV local to the embedded entry point relative to the other LDZ entry CVs.

While these alternative approaches do not consider an annual use profile of a consumer when generating the Charging Area, they could offer a systematic level of protection from unfavourable misallocation and so mitigate risk of over-billing. These methods would need to be assessed in more detail, as part of a feasibility study.

8.2.2 Option 2 Composite – Separate Charging Areas for Supplies into the LDZ

The Composite Option can be viewed as a logical extension to the Pragmatic Option.

The original aims of the Composite Option were:

- simple to define and remain fixed with consumers allocated to an entry point or FWACV until significant changes in the network or biomethane entry flow is noted,
- equitable to consumers in the different Charging Areas,
- Charging Areas supported by a level of additional strategic within-network measurements.

This method uses network modelling to configure Charging Areas around each input point to the LDZ, whether these are Offtakes from the NTS or embedded entry points. This option would require moderate to significant investment in "within-network" CV measurement devices, depending on LDZ size and system configuration and is summarised below in Figure 63.

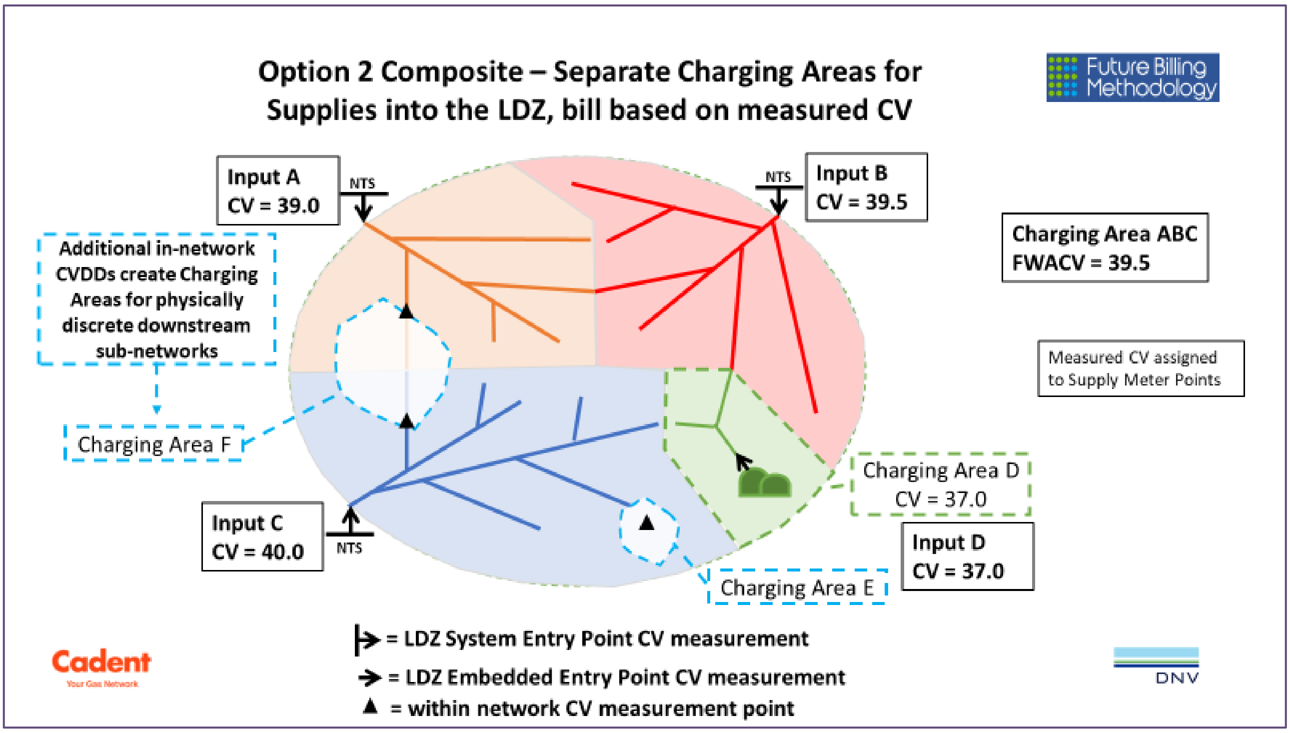

Figure 63 – Option 2 Composite – Separate Charging Areas for Supplies into the LDZ

Under this approach the LDZ could be sub-divided into smaller CV zones by:

- Creating Charging Areas based on NTS Offtakes into individual LDZs. This would require the identification of the networks within the LDZ that receive gas from each NTS Offtake. Where gas is received from more than one Offtake, a methodology would need to be developed to allocate individual consumers to an individual Offtake. A Charging Area would need to be defined akin to the approach developed for the Pragmatic Option.
- Creating Charging Areas for single fed networks or a group of networks with an isolated feed by installing CV measurement at the selected Pressure Reduction Stations (PRS) feeding them. The use of within-network CV measurement to support billing could require a change to the Gas (COTE) Regulations as these would not be measurements at entry points but could enable all downstream consumers to be billed on a more locally received CV.

- For isolated networks fed by two or more PRSs, consideration could be given to the development of a local FWACV Charging Area for that network. This would require CV measurement at each PRS and calculation of FWACV for those consumers. This would be an implementation of the existing FWACV rules but at a more local level.
- Supply Meter Points would be attributed the CV of the relevant Charging Area entry point.

Unlike Option 1 Pragmatic, where an exploratory financial review of the impact on the consumer's bill is integral to the Charging Area definition, the field trial data is not at an LDZ level so does not enable a comparative review of the potential impact on a consumer's gas bill for Option 2 Composite. However, with the additional billing CVDDs it is envisaged that any disparity in consumer billing would be improved through the more localised Charging Areas and would not be extended beyond the disparity under the current FWACV methodology.

8.2.3 Option 3 Ideal – Local CV Measurement Charging Areas

The Ideal Option envisaged a further development on the Composite Option, which could support a smart-metered network, with CV measurement installed locally throughout the network, from which CV data could be transmitted to smart meters and/or to Smart DCC, so that the consumer could ultimately be billed directly on current gas energy use, rather than measured volume and allocated CV.

Originally this method considered the transmission of CV data from local measurement points to consumers' smart meters to enable a further transition to full gas energy metering & billing at the point of use (this latter point is the subject of the MS11 Smart Metering Laboratory Trials Report). The method is summarised below in Figure 64.

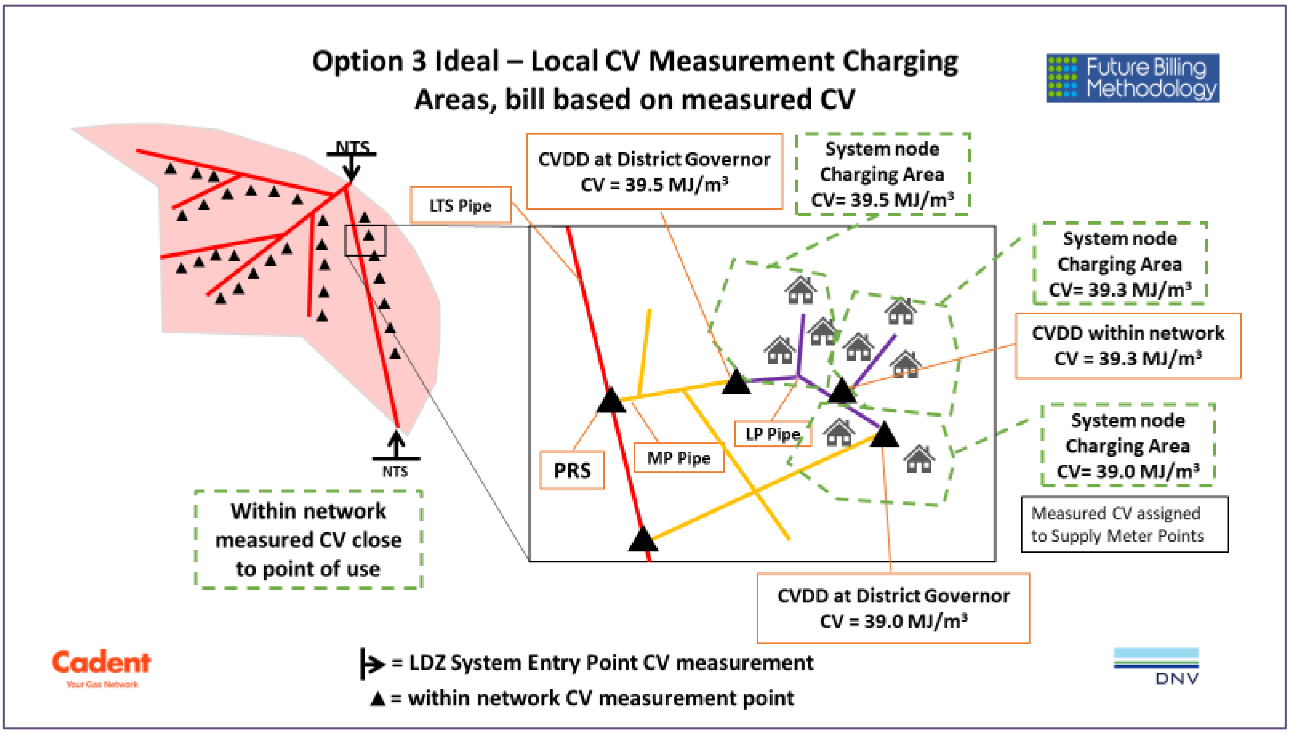

Figure 64 – Option 3 Ideal – Local CV Measurement Charging Areas

This option would require additional CVDD installed at strategic locations, to complement those already installed under the Composite Option, to underpin a more specific attribution of CV to customers' smart meters. This would include the identification of isolated single fed areas and network analysis to create appropriate Charging Areas for the allocation of the SMP to an appropriate local CVDD.

This option was considered as a longer-term development that would be an enabler for whole-scale smart gas energy metering. Under this approach, with the widespread installation of additional billing CVDD measurement devices it is expected that disparities in consumer billing would be removed through the creation of localised Charing Areas. However, this arrangement would entail very significant additional investment in the gas network and the development and implementation of a Great Britain Companion Specification use case and corresponding changes to the Smart Energy Code.

The key findings from the MS11 Smart Metering Laboratory Trials Report were that the capability exists, in principle, to deliver locally-derived calorific value data to gas smart meters (GSME), and to convert this to a kWh value which could then be used for direct billing purposes. However, a number of technical challenges/limitations including, though not limited to, meter battery life, data reading traffic load and metering specifications for kWh retrieval, require further exploration and understanding. Potentially this option may not be workable within the timeframe given the requirement to also consider the implications of a future move to hydrogen transportation, which would involve the roll-out of hydrogen-specific meters. For further detail see MS11 Report on Completion of Smart Meter Laboratory Trials.

8.3 Modelled CVs used for Consumer Billing

During the development of this project, specifically the network modelling aspects, a fourth concept for defining Charging Areas has evolved. In contrast to the above three methods, this approach would generate a modelled CV for billing purposes.

8.3.1 Option 4 - Modelled CV for Consumer Billing using Online LTS model

This approach uses online network modelling of the LTS to calculate the CV received at both individual LTS PRSs into the lower pressure tiers and direct LTS-connected consumers. This would combine the measured CV values along with measured pressures and flows to calculate the CV at defined periods of time, for example hourly or daily, delivered by the LTS. All consumers within the downstream pressure tier networks would be assigned to a LTS PRS for billing purposes and the billing CV would be provided by the online system. In instances where there is mixing of gas on the lower pressure tiers with other gases of different CVs, this would require additional downstream CV modelling such as the methods described above for the Pragmatic options. This combines the requirement for the use of CV measurement and the online operation of the network. This method is summarised below in Figure 65.

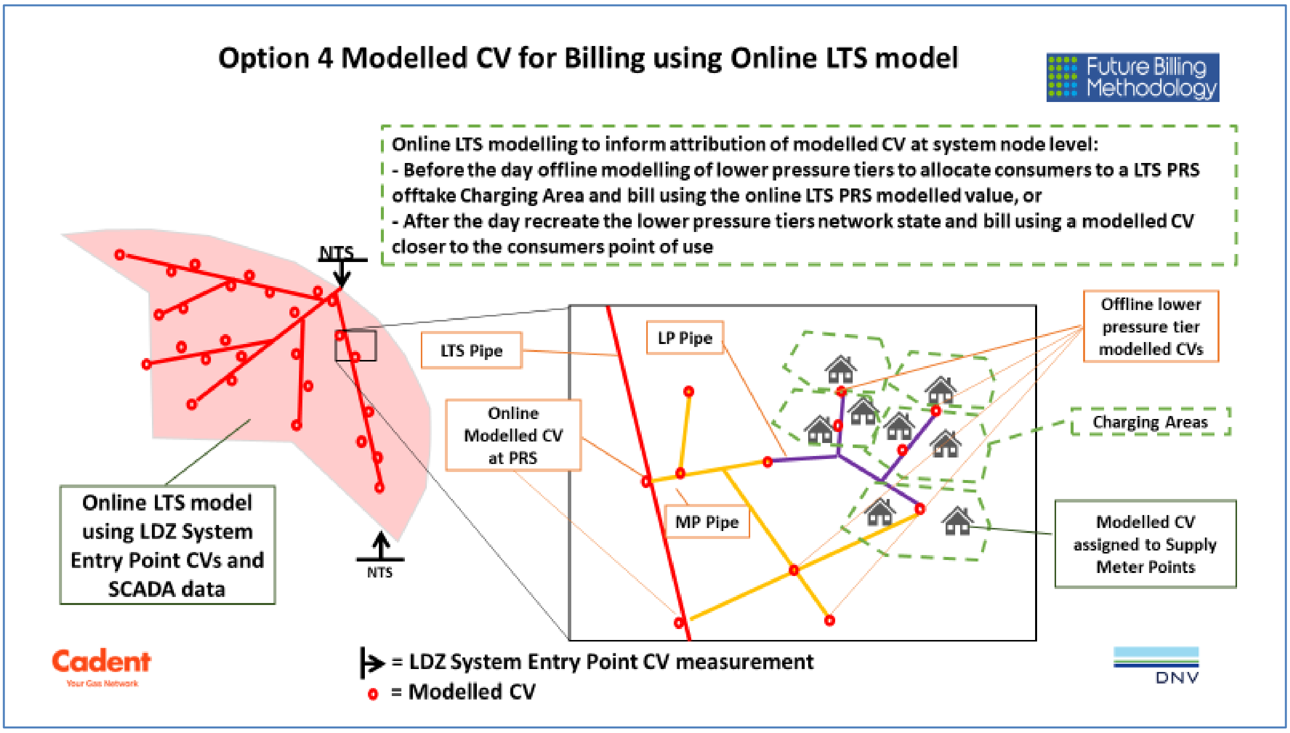

Figure 65 – Option 4 Modelled CV for Billing using Online LTS Network Model

For pressure tiers downstream of the LTS, the allocation of a billing CV could either be done through:

- Undertaking upfront offline modelling of lower pressure tiers to allocate consumers to a Charging Area. All consumers within the downstream pressure tier networks would be assigned to a LTS PRS for billing purposes and the billing CV would be provided by the online system on a daily basis. In instances where there is mixing of gas on the lower pressure tiers with other gases of different CVs, this would require additional downstream CV modelling such as the methods described above for the Pragmatic Option. In addition, for isolated networks fed by two or more PRSs, consideration could be given to the development of a local FWACV Charging Area for the downstream SMPs; the implementation of the existing FWACV rules but at a more local level. This method of defining Charging Areas, is similar to that envisaged by the original FBM Composite option.

- Recreating the lower pressure tiers network state after the day using the CVs from the modelling of the LTS as an input to the downstream pressure tier models. In this case, each network analysis model system node would become a Charging Area in its own right. All SMPs within the network would be assigned a billing CV based on the after the day network analysis modelled CV value for the system node to which they are assigned. This method of defining Charging Areas, is similar to that envisaged by the original FBM Ideal option, with the exclusion of smart metering, replaced with a modelled CV value local to the point of use.

If feasible, either approach to a modelled CV could provide both the benefits sought by the Pragmatic option and provide a consistent methodological pathway to facilitate hydrogen blending at higher tiers of the gas distribution network.

As with Option 2 Composite, the field trial data is not at an LDZ level so does not enable a comparative review of the potential impact on a consumer's gas bill. However, fundamental to this approach is that the modelled CV is more closely aligned to the received CV and it is envisaged that any disparity in consumer billing would be improved through the more localised Charing Areas and should not be extended beyond the disparity under the current FWACV methodology.

Subject to industry and regulatory requirements, future development towards the use of modelled CV for consumer billing could involve a CV validation exercise[14] in specific limited trial areas, identified and evaluated using network data and predictive modelling of zones of influence exerted by specific gas entry points. However, to enable a full-range comparison between measured and modelled CV values, this would require the LDZ CV cap to be "turned off", which could require a change to secondary legislation, to provide the necessary derogation facility within the thermal energy regulations and enable development of the appropriate statutes and verification framework to regulate a modelled CV regime.

8.4 Identification of Consumers within a Charging Area

Having agreed the most suitable method to define a Charging Area, Figure 66 gives high-level steps to identify the consumers for the specified Charging Area. These high-level steps are appropriate for all methods as they provide the link between the network analysis model system node and a SMP.

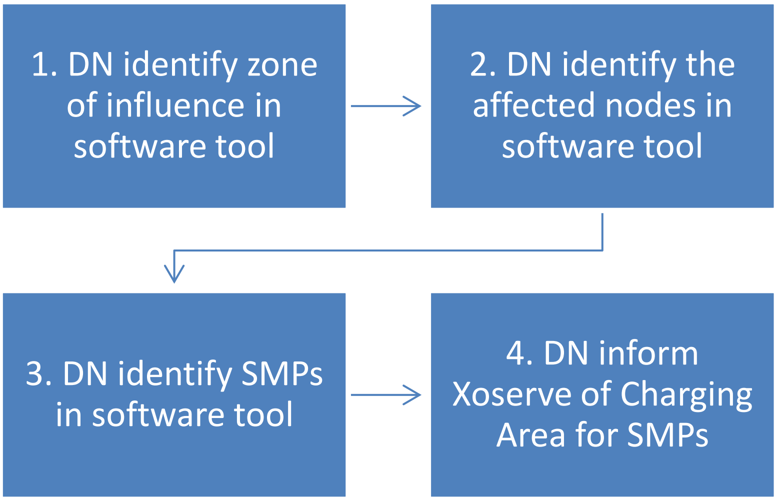

Figure 66 – Simple Process Flowchart for the Identification of Consumers in a Pragmatic or Composite Charging Area

Step 1 Use the network analysis tool to identify the CV Charging Area of the specific embedded entry or CV measurement point (post entry connection acceptance for any new supplies).

Step 2 Use the network analysis tool to identify the nodes within the defined CV Charging Area.

Step 3 Interrogate the demand tool to generate a list of SMPs associated with the nodes within the defined CV Charging Area.

Step 4 Provide Xoserve with a list of SMPs and their associated Charging Area entry point CV or modelled CV value for billing purposes.

8.5 Options Summary Table with Initial High-Level Cost Analysis

Table 13 below summarises the FBM Project billing options and advantages / disadvantages of each option to aid the industry consultation on the way forward. It provides a condensed view of the different approaches, to allow a simple comparison between them when read across the table, or a list of pros and cons for an individual approach when read

[14] Compliance with existing Gas (Calculations of Thermal Energy) Regulations unavoidably limited the scope of CV modelling validation for the FBM Project, as the enrichment of low-CV gases cannot be turned off without triggering the CV cap and incurring LDZ-wide impacts on CV shrinkage – hence the application of molecular oxygen measurement to differentiate biomethane from natural gas.

down the table. A more detailed understanding behind the pros and cons can be gained from the body of the main document.

This technical report has assumed that system architecture, Network Code changes, system requirements for Xoserve, Shippers and Suppliers etc. is the same for each option so related advantages and disadvantages have not been included in the table.

For each method, a high-level indication of the costs have been included. This information has been based on the Cost Benefit Analysis undertaken for the Ofgem Stage-gate in 2017[15]. These figures are to be updated for the CBA in the FBM final project report, but give an indication of the order of magnitude of the possible costs involved with each method. The original CBA also provided a monetised view on the potential carbon savings gained through the implementation of FBM. This will also be updated for the final project report CBA.

[15] Included within the report NIC04 – Project Progress Report 1 December 2017; https://futurebillingmethodology.co.uk/wp-content/uploads/2017/12/FBM-Project-Progress-Report-Final-v2.pdf

	Methods for Defining a Charging Area				
	Measured CV applied to Consumer Billing			Modelled CVs applied to Consumer Billing	
	1 - Pragmatic	2 - Composite	3 - Ideal	4 - Modelled CV for Billing using Online LTS Model	
				(C) Before the Day	(D) After the Day
Method Summary	• Applies to specific input points e.g. embedded entry sites. • Network modelling & financial analysis used to generate embedded charging area • Customers billed on measured CV at input to charging area or FWACV of parent LDZ accordingly	• Network analysis informs tactical location of CVDDs within the network • CVDDs attribute CV for billing within sub-LDZ charging areas	• CVDDs located throughout network to measure CV for billing close to point of use	• Use measured CV and flows at LDZ system entry as inputs to modelling. • Use of online modelling of LTS to derive a CV value at each LTS exit point. • Predictive modelling of downstream networks to create charging areas for each LTS exit point	• Use measured CV and flows at LDZ system entry as inputs to modelling. • After-the-day reconstruction of the network state to generate output CV values for each meter point
Advantages	• Upfront analysis of the network models	• Upfront analysis of the network models	• Upfront analysis of the network models	• Upfront analysis of the below LTS network models	
	• Applicable to low and high CV embedded entry and embedded hydrogen blending	• Applicable to low and high CV embedded entry and H2 blends	• Applicable to low and high CV embedded entry and H2 blends	• Applicable to low and high CV embedded entry and H2 blends	• Applicable to low and high CV embedded entry and H2 blends
	• Fixed allocation of SMPs to Charging Area; annual or periodic re-assessment of Charging Areas	• Fixed allocation of SMP to Charging Area; annual or periodic re-assessment of Charging Areas	• Most equitable approach for Consumer billing as the CV is measured close to the point of use	• Fixed allocation of SMP to Charging Area; annual or periodic re-assessment of Charging Areas	• Most equitable approach for Consumer billing as the CV is modelled close to the point of use
	• Can be undertaken with existing network modelling software	• Can be undertaken with existing modelling software	• Can be undertaken with existing modelling software		
	• Consumer Billing CV would be a measured value from a CVDD closer to point of use	• Consumer Billing CV would be a measured value from a CVDD more local to point of use	• Consumer Billing CV would be a measured value from a CVDD very close to point of use	• Consumer Billing CV would be a modelled value for the relevant LTS exit point, closer to the point of use	• Consumer Billing CV would be a modelled value very close to the point of use

	Methods for Defining a Charging Area				
	Measured CV applied to Consumer Billing			Modelled CVs applied to Consumer Billing	
	1 - Pragmatic	2 - Composite	3 - Ideal	4 - Modelled CV for Billing using Online LTS Model	
				(C) Before the Day	(D) After the Day
Advantages	• Embedded Charging Area is determined by network modelling to predict CV at each system node throughout the review period, then analysing bill impact on one typified customer at each node on the relevant network. • Annual use analysis is theoretically the most equitable method for customers. (Alternatives in Appendix D.)	• Charging areas determined by predictive network modelling. • Billing CV provided by tactically-located CVDDs upstream of each Charging Area	• Charging Areas highly localised.	• Measured CVs used to generate a modelled billing CV for each downstream Charging Area based upon continually updated online LTS modelling	• Measured CVs used to generate a modelled billing CV at system node level based upon continually updated online LTS modelling
				• Modelling CV across the LDZ for billing would be cheaper and 'greener' than the installation of a large number of physical CVDDs (assuming existing technology)	• Modelling CV across the LDZ for billing would be cheaper and 'greener' than the installation of a large number of physical CVDDs (assuming existing technology)
			• Consistent platform for handling the full transition to gas decarbonisation	• Consistent platform for handling the full transition to gas decarbonisation	• Consistent platform for handling the full transition to gas decarbonisation
				• Existing commonality of node names on LTS and Gemini system	• Existing commonality of node names on LTS and Gemini system
Disadvantages	• Fixed Charging Area that assumes minimal changes in network / demand dynamics	• Fixed Charging Area that assumes minimal changes to physical network / demand dynamics		• Fixed Charging Area on the below LTS system that assumes minimal changes in network / demand dynamics	
	• Risk that actual variations in input CV and network state may differ from when the Charging Area is created	• Risk that the variable network state on the LTS may not be taken into account when the Charging Area is created		• Risk that the variable network state on the LTS is not taken into account when the Charging Area is created	

	Methods for Defining a Charging Area				
	Measured CV applied to Consumer Billing			**Modelled CVs applied to Consumer Billing**	
				4 - Modelled CV for Billing using Online LTS Model	
	1 - Pragmatic	**2 - Composite**	**3 - Ideal**	**(C) Before the Day**	**(D) After the Day**
Disadvantages	• Requires annual network demand profiles and energy use profiles for different consumer types	• Requires a consistent approach for complex upfront offline modelling to define Charging Areas below the LTS		• Requires a consistent approach for complex upfront offline modelling to define Charging Areas below the LTS	
		• Requires additional modelling to Pragmatic to create CV Charging Areas		• Requires additional modelling to Pragmatic to create CV Charging Areas	• Network modelling to create CV Charging Areas would be highly labour intensive, unless automated
	• Additional network analysis required compared to alternatives considered in Appendix D to generate Charging Area; could be mitigated through automation	• Additional network analysis required from NTS offtake down through the pressure tiers as well as steady state modelling of lower tiers		• Additional network analysis required from NTS offtake down through the pressure tiers as well as steady state modelling of the lower pressure tiers	• Complex network modelling to recreate the LDZ network-state after the day to generate the billing CV by network node / meter point
		• Cost of installation, powering and maintenance of ~10,000 additional CVDD equipment units	• Cost of installation, powering and maintenance of ~44,000 additional CVDD equipment units		
		• Assuming current technology - emissions from additional CVDD venting up to 130 ktCO2e; CoC ~£9.2m per year.	• Assuming current technology - emissions from additional CVDD venting up to 580 ktCO2e; CoC ~£40.6m per year.		
			• Technical challenges/limitations of assigning a CV to a smart meter		
				• Requires implementation of suitable LTS online software	• Requires implementation of suitable LTS online software
				• Consumer Billing CV is not from a measured CVDD	• Consumer Billing CV is not from a measured CVDD
					• Highly system intensive

	Methods for Defining a Charging Area				
	Measured CV applied to Consumer Billing			Modelled CVs applied to Consumer Billing	
	1 - Pragmatic	2 - Composite	3 - Ideal	4 - Modelled CV for Billing using Online LTS Model	
				(C) Before the Day	(D) After the Day
Disadvantages					• Significant amount of network related data required to recreate the LDZ network-state on a daily basis
	Early High Level Indicative Costs (Based on 2017 Initial CBA)				
CAPEX £m	£58.0m	£393.9m	£799.1m	£81.3m	£81.3m
OPEX (Set-up) £m	£0.3m	£1.2m	£3.3m	£1.2m	£3.3m
OPEX (Ongoing) £m	£2.4m	£6.9m	£12.8m	£4.5m	£5.3m

Table 13 – FBM Options Summary Table with Initial High-Level Cost Analysis

9 FACTORS TO BE CONSIDERED IN IMPLEMENTING A FUTURE BILLING METHODOLOGY

9.1 Overview

The progression through the previous sections in this report has illustrated that it is possible to use the network analysis modelling to show, with confidence, the variation in CV received by consumers across a network. Section 8 has described several methods for defining the Charging Area along with a table of pros and cons to aid industry discussion.

Below are a number of modelling and operational factors that need to be considered and their impact reviewed through industry consultation. Many of these issues were raised through the initial industry consultation in 2017 and other factors that have been developed over the project timeframe.

9.2 Network Model and Parameters

DNs have network analysis models which already perform a critical planning & design role underpinning safety and security of supply and which can closely simulate how the network performs under varying demand conditions. The network models contain a number of parameters, for example:

- pipes and associated parameters,
- demands, demand categories and demand scaling,
- source pressures and flows,
- operating regimes,
- gas properties, including CV.

For the definition of a Charging Area, the model used, and its associated parameters will need to be agreed through industry understanding and consultation to ensure a consistent approach is taken by all DNs.

The modelling parameters already used for other DN activities, such as Shrinkage and Leakage Modelling, could be considered in the application of Option 1 Pragmatic or Option 2 Composite when defining a Charging Area.

For consideration with modelling of the CV across the year for Option 1 Pragmatic, and where appropriate for Option 2 and Option 4, is the development of an automated approach, including variations in demand to generate the CV profile and financial bill impact. Within the MS13 network analysis, the processes followed have highlighted the difficulties in trying to replicate the localised within day demands and flows at a low pressure level without additional data availability. The different types of data items, frequency of time period and therefore volume of data increases as the level of network modelling increases with complexity such as in Option 4 Modelled CV for Consumer billing. Both these options would also require significant network modelling that would need to be part of an automated process. The upfront allocation to a Charging Area would be a simpler approach than recreating an ‘after the day’ model on a daily basis, even if automated.

An automated approach would need to take into account the items discussed in the following sub-sections.

9.3 Additional Network Configuration Considerations

When developing a Charging Area around an embedded entry point several additional factors will need to be considered. The operational parameters of the supply itself as well as the interconnectivity in the network it feeds into.

Some examples of network configurations with embedded entry point:

1. **Multiple downstream blending points within network.**

The Chittering biomethane entry into the Cambridge network is an example of this i.e., the low CV gas from Chittering would be mixed with NTS gas as it is transported into Cambridge and then further into the network this mixed gas blends again with other sources of NTS gas. Each time a blend occurs the CV of the low CV gas increases. This means that consumers further from the entry point will receive gas with a CV nearer to the NTS gas CV than the low CV of the biomethane.

The complexity of this configuration increases as the number of embedded entries with a network increases e.g., a network with two or more embedded entry points.

2. Low CV feed into network where there is little (blending) interaction with other sources.

In this example the size and variability of the Charging Area is determined primarily by the operational setup at the embedded entry point. i.e.

a) Pressure controlled entry point

The embedded entry operates with a fixed outlet pressure with the flow into the network determined by the downstream capacity and local demand conditions. In this scenario, the zone of influence of the entry point remains similar even as demand varies. The Charging Area would be more stable in this regime.

b) Volume controlled entry point

This tends to be applicable to process driven supplies where it is difficult to alter the flow rate to suit network conditions and the network has to absorb the same flow under all demand conditions. In this example, the zone of influence will increase in size as demand reduces. The flow from other sources will need to reduce as demand drops to allow the required biomethane flow to be delivered. This can be managed by either manual intervention by control room staff or through a system-wide control system.

When determining a fixed Charging Area under this regime several methods for defining the area could be considered. These include, though not limited to:

i. Zone of low CV under peak demand conditions (winter) – small zone

ii. Zone of low CV under min demand conditions (summer) – large zone

iii. Zone of low CV under average demand conditions – intermediate zone

As detailed in section 8, the application of a financial analysis reduces the potential in-equitability and cross-subsidy between consumers. In such a scenario where the zone of influence is more stable, basing a Charging Area on the average demand conditions might be the simplest way to proceed.

3. Connection of biomethane site to a pipeline where flows are sufficient to allow blending to an acceptable CV.

For sites that currently propanate to achieve an appropriate gas CV but feed into a pipeline (perhaps an IP or LTS pipeline) that has a significantly larger flow rate than the biomethane site then it might be possible to consider the option of blending using network gas rather than propanation at the embedded entry point. It would be necessary for the transmission operator to manage gas flows to achieve an acceptable blended CV and an additional CV measurement would be required downstream of the network blending point.

9.4 Management of Charging Areas

In the current FWACV billing methodology the LDZ is the Charging Area and all consumers identified within that LDZ are billed on the FWACV for that area. If new properties are built and supplied with gas within the LDZ they are allocated to the appropriate LDZ Charging Area.

In all the options this principle will remain. However, there will be a requirement to monitor any changes in the Charging Area to ensure that the boundary remains appropriate. It is proposed that the Charging Areas are reviewed at least annually or when the following occurs, to check whether there is any requirement to amend the area:

- Increased / decreased network demand,
- Network reinforcement / replacement / abandonment projects altering the network flow pattern,
- New embedded entry supplies,
- Change in entry flow requirements i.e., increased / decreased flow rates, change in operational control method etc.

9.5 Any Additional Sensors?

The Future Billing Methodology project was set up using measurements of oxygen concentration within both the Cambridge and Lincolnshire networks to show that the DNs network analysis models could be used to simulate the change in oxygen concentration across a network and as a consequence also the variation in CV.

The project has been successful in that results from the network modelling have shown a credible validation against the measured oxygen sensor values.

Since the network analysis models are able to predict network behaviour it is proposed that these models are used to generate Charging Areas where required and that for Charging Area determination under Option 1 Pragmatic, no further within-network measurements will be required.

Both Option 2 and Option 3 rely on the installation of additional CV measurement for billing purposes. As detailed in section 8 the installation at scale of currently available CVDDs has significant capital and operating costs for their installation, powering and maintenance, along with necessary gas venting.

An alternative approach to the installation of CVDDs could be to identify SMP CVs through network modelling across the pressure tiers as detailed under Option 4 Modelled CV for Consumer Billing using Online LTS network modelling. The calculation of the CV delivered by the LTS would generate robust CV values while negating the need for additional sensors, or a large number of additional sensors.

Consideration could be given to the inclusion of temporary CVDDs at strategic points within the network to validate the Charging Area CV values whichever route is taken for defining a Charging Area.

9.6 Shrinkage Issues

9.6.1 Overview

When considering the impact of a change to the billing methodology it is important to understand the current position regarding shrinkage.

The NTS shrinkage scheme incentivises minimising energy costs associated with operation of the network. As shrinkage provider, National Grid are responsible for managing the end-to-end service of forecasting, accounting for, procuring, and supplying energy to satisfy the daily NTS shrinkage components.

NTS shrinkage energy (gas and electricity) is bought by the gas transmission system operator. NTS shrinkage is procured for three components:

- Compressor Fuel Usage is the energy used to run compressors to manage pressures within the gas transmission system. This can either be gas or electricity, depending on the power source for the specific compressor.
- Calorific Value Shrinkage is gas which cannot be billed due to application of CV capping under the Gas (Calculation of Thermal Energy) Regulations 1996 (amended 1997).
- Unaccounted for Gas is the remaining quantity of gas which is unallocated after taking into account all measured inputs and outputs from the system.

Only the Calorific Value Shrinkage value is considered in the Future Billing Methodology project since all the other components of shrinkage will continue to be determined by National Grid and the DNs using their existing evaluation tools.

9.6.2 Issues for FBM

Under the current FWACV Regime, CV Shrinkage can be understood as the difference between Measured Energy IN and Billed Energy OUT where the LDZ FWACV cap has been triggered by a low-CV gas input.

- Energy IN – Total Energy delivered to the DN through Offtake or embedded entry points (Measured CV and flow at all entry points)
- Energy OUT – Total Energy billed to consumers. This energy value is currently determined by the meter reads (flow) and the Billing FWACV.

If the entry CVs are maintained such that the difference between the lowest entry CV and the overall LDZ FWACV is less than 1MJ/m3 then the overall energy balance is maintained, and consumer bills are deemed equitable.

The LDZ FWACV cap limits the adverse impact on consumer bills due to CV variation by ensuring that the billed CV value for the LDZ can be no more than 1MJ/m3 above the lowest CV gas source. However, the impact of triggering the CV cap passes the unbilled energy in the LDZ to the NTS CV Shrinkage account, and even a very small volume of gas at a low CV entry point will affect the billing CV for the whole LDZ.

Under the FWACV regime the energy inputs are clearly defined, and the billed energy is also available from the Xoserve systems. The FWACV method ensures that, as long as the CV cap is not triggered, total energy in = total billed energy out.

For FBM Option 1 Pragmatic, the FWACV Charging Area would be based on the LDZ as now but with the removal of consumers within a determined boundary around the embedded entry point. Within this boundary, customers would be charged using the embedded entry CV rather than LDZ FWACV.

Since the Charging Area boundary is proposed as fixed, there could be times of the day / week / month / year where gas from the embedded entry would be supplied to consumers who are allocated to the FWACV Charging Area (and vice versa). This would mean that, depending on the basis for defining the new embedded Charging Area, on any day there could be consumers allocated to the embedded entry point who receive gas from outside the embedded Charging Area. At an LDZ level this could cause a small imbalance, which would impact residual levels of unidentified gas (UIG).

For Option 2 Composite, the large number of CV and flow measurements could provide greater resolution on energy balancing at a more local scale. However , any imbalance in the Energy IN = Energy OUT equation would affect residual levels of UIG, as above.

For Option 3 Ideal in which billing would be based on local CV measurement throughout the LDZ, CV Shrinkage calculations should in principle be obviated. However, even at this level of CV measurement, there could be some highly localised degree of mis-allocation due to flow changes between system nodes, for example. Again, this could impact UIG.

For Option 4 Modelled CV, at an LDZ level, any inaccuracy in CV allocation could create an imbalance in the Energy IN = Energy OUT equation, and result in a change in UIG, as for the other options.

Any FBM option would need to be subject to rigorous pre-implementation testing and may require an assurance framework. This could be strategically targeted and cost-proportionate, for example, by the use of mobile CV measurement apparatus within the network, subject to appropriate, approved technology being available / developed.

9.7 Xoserve, Shippers and Billing Systems

The delineation of new Charging Areas within each LDZ must be firmly linked to consumers' SMP data in a way that can drive the daily energy attribution and Meter Point settlement processes. Early work is underway to investigate how this can be achieved and to inform the high-level implementation cost-benefit analysis (CBA) that is a key overall FBM project output.

9.8 Entry Capacity

As stated in Section 7 the network model is able to demonstrate the network capability i.e., with an entry volume of low or high CV gas the network dynamics could be modelled. The impact that CV will have on flow volumes is not limited to biomethane, but relevant to all GS(M)R compliant gases.

Assuming that the booked entry capacity at the biomethane site includes a volume to allow for propanation then removal of the requirement for propane injection will result in one of the following:

- Reduce the total volume being injected – with the biomethane plant not able to generate additional volume of biomethane.
- Allow an increase of biomethane production (if possible) up to current booked capacity.
- Allow an increase of biomethane production above the current booked capacity to supply the higher volumes of low CV gas required to meet the network demand.

9.9 Multi-Embedded Entries

Consideration should be given to the interaction of multiple embedded entries within a network. Where the Charging Areas for these sites do not overlap then these can continue to be separate. Where two or more embedded entry points interact, and the Charging Areas overlap then consideration could be given to creating a new area for these and using a local FWACV for billing purposes. For biomethane entry this local FWACV value will be lower than the FWACV value used for the rest of the LDZ.

9.10 Operational Issues

9.10.1 Entry Point Offline / Low / High

While recognising that the loss of a CV measurement at an entry point will impact on the billing accuracy, this possibility is not unique to embedded entry points. The current Xoserve process would manage the value until such time as the CV measurement was restored. This would also apply to the entry flow measurement.

9.10.2 Operational Flow Differs from Contracted / Predicted Flow

In circumstances where the operational flow differs significantly from the contracted flow that has been used as the basis for the predictive network modelling this could invalidate the defined Charging Area; a new one could be created, and revised SMP group details provided to Xoserve.

9.10.3 Network Configuration Changes (Pipe / Demand)

As discussed in section 9.4, if there are significant changes that alter the dynamics of the network such that the defined Charging Area is no longer valid, a new one should be created, and revised SMP group details provided to Xoserve.

9.10.4 Compression of Gas into an Upstream Network

In the case where the local network is unable to absorb the full entry point flow under all demand conditions the DN may choose to install compression from the pressure system the embedded entry is connected to a higher-pressure tier. In the example of a biomethane embedded entry, typically, the compressor will operate at times of low network demand and allow the excess gas from the biomethane plant to be transported to consumers in the upstream system.

In networks where within-network compression is utilised this should be included in the network model and therefore would be part of any definition of a Charging Area. Whether any upstream consumers are included in a Charging Area would depend on the consequential impact on the CV of the higher pressure tier gas.

10 CONCLUSIONS AND RECOMMENDATIONS

Network modelling provides an understanding of how the network performs and the results can be compared over periods of time. It uses average generic demand profiles (domestic, commercial, industrial) which generate results that are similar to those experienced. In simple terms, the localised instantaneous effect of, for example, a house boiler turning on, cannot be replicated through the averaging techniques applied in industry accepted modelling.

The analysis in this report has demonstrated that it is possible to use network modelling to show, with confidence, the variation in CV received by consumers across a network and that network energy modelling is able to define a Charging Area for billing purposes. The following sections provide a summary of the conclusions from that analysis and set out recommendations for consideration during the industry consultation period. Some additional work areas are set out that might be required as part of that consultation or before any change to the billing methodology.

10.1 Conclusions

Network Analysis Modelling

It has been demonstrated that network modelling – which already performs a critical planning & design role underpinning safety and security of supply – can closely simulate how the network performs under varying demand conditions. The existing network model of Cambridge is able to simulate the variation of CV of gas in the Cambridge network at different demand levels over a year. A Charging Area could be developed around such an embedded source of gas, which would remove the need for enrichment and could constrain billing disparities to within the range experienced under the existing LDZ FWACV regime.

The network modelling has been shown to be highly accurate for the material extent of the biomethane range but is slightly conservative in predicting its reach. These results provide confidence that the model can accurately reflect reality in terms of the presence / absence or concentration of biomethane gas across the network. For the very low oxygen concentration levels, where the network modelling was less accurate, the impact of the biomethane on the CV of the mixed gas would be negligible. This strong correlation demonstrated between measured and modelled oxygen levels gives confidence that network modelling can accurately predict or simulate the travel and mixing of gases under varying demand conditions and, with appropriate software, can robustly attribute CV at system node level.

The report has developed, at a high-level, several methods for identifying Charging Areas for future billing purposes. This Proof-of-Concept Project is a key step along that pathway.

Charging Area Definition for a Future Billing Methodology

One of the key NIC objectives was to work within the current Gas (Calculation of Thermal Energy) Regulations requiring allocation to a physical CVDD when defining a Charging Area. However, at this point, there exists a range of views as to whether there is any scope within these regulations for the use of network modelling for Charging Area allocation. The following options all rely on network modelling to allocate a consumer to a Charging Area with their billing CV measured at a CVDD:

- Future Billing Option 1 Pragmatic – would use network CV modelling to determine an embedded Charging Area within the LDZ but would apply the existing CV measurement at the embedded gas source for billing consumers within that Charging Area. All other consumers would be billed on the LDZ FWACV.
- Future Billing Option 2 Composite – would use a combination of network CV modelling described for Option 1 Pragmatic and the identification of single fed sections of the LDZ to determine Charging Areas. These Charging Areas would require additional CV measurement for all consumer billing.
- Future Billing Option 3 Ideal – would use network modelling to determine the optimum location for CV measurement devices to be installed locally throughout the network. From these devices CV data could be

transmitted to smart meters and/or to Smart DCC, so that the consumer could ultimately be billed directly on current gas energy use, rather than measured volume at an allocated CV.

Table 13 shows that the additional CV measurement requirement within Options 2 and 3 would drive very significant capital and operating costs for the installation, powering, maintenance and replacement of CV measurement devices, and unless gas venting could be obviated by advances in technology, the levels of vented gas for CV measurement purposes would be unsupportable.

An alternative approach considered in this report is the use of measured CVs at the LDZ entry points combined with online network modelling of the LTS to generate modelled CVs for billing purposes.

- Future Billing Option (4) – Modelled CV, would use online LTS modelling with SCADA data to provide a continually updated values of modelled CV on the exit points from the LTS to the lower pressure tiers. This would combine the measured CV values along with measured pressures and flows to calculate the CV at defined periods of time, for example hourly or daily, delivered by the LTS. Allocation of a billing CV can either be done through:
    - Undertaking upfront offline modelling of lower pressure tiers to allocate consumers to a Charging Area assigned to a LTS offtake for billing purposes. The billing CV would be provided by the online LTS system.
    - Recreating the lower pressure tiers network state after the day using the CVs from the modelling of the LTS as one of the inputs to the downstream pressure tier models. In this case, each network analysis model system node would become a Charging Area in its own right and modelled CVs would be attributed to individual SMPs across the gas network.

Pathway to Decarbonisation

In the future there will be a wide range of gases introduced into the UK gas networks, including Hydrogen Blend and pure Hydrogen (physically separate network). Any future billing system would need to accommodate a number of different billing CVs and be able to assign groups of SMPs to a particular entry point. To enable fair and equitable billing across the gas supply chain under such a diversity of supply, the gas billing system architecture will require the capability to attribute an individual CV to each SMP for billing purposes. From the initial Stage-Gate of the FBM project, it was understood that SMPs could be assigned a billing CV different from the LDZ FWACV, reference XRN4323 - CV Zones (FBM) V1.8 AP .pdf from Xoserve. This understanding had guided the progression with the Charging Area definition options. More recent discussions with Xoserve have identified that significant system changes would be required to accommodate a number of different Charging Areas and to be able to assign groups of SMPs to a particular entry point for billing purposes.

Future transportation of pure hydrogen would effectively step over the transitional complexities of mixing gases of different CVs within the same pipeline network. In the mean-time and for those networks which would not ultimately transition to hydrogen gas distribution, the transition to net zero will require sections of networks and / or discrete networks to be shared by gases of differing CVs. For example, hydrogen blending at LDZ input points, sectorised parts of networks during conversion to hydrogen, partially or exclusively fed local biomethane networks with differing CVs. CV attribution at SMP level would be able to support the range of transitional arrangements, including transition to full hydrogen transportation where practicable, and longer-term diversity of gas supply for those networks that do not convert to hydrogen. It is understood that the current billing systems do not have this capability and therefore new functionality would be required whatever future billing option is taken forward.

Given the pressing need to decarbonise heat, the primary focus must be to identify the most appropriate and sustainable option for future gas billing which will include essential systems architecture changes to allow individual SMP billing CVs and may require an amendment to the Gas (Calculations of Thermal Energy) Regulations. In making the following recommendations, it has been assumed that for each Charging Area option the same system architecture, Network Code changes, system requirements by Xoserve, Shippers and Suppliers etc will be required.

10.2 Recommendations

As detailed in Table 13, each of the methods for defining a Charging Area offers different ways of delivering a future billing methodology, with varying levels of precision, complexity in implementation and overall cost.

In assessing the feasibility of Option 1 Pragmatic, it is acknowledged that Cambridge and Lincolnshire networks are examples of an integrated and a more geographically spread network respectively. The basic principles for Charging Areas for these networks have been set out and learning from this project has shown that it may not be possible to create a simple procedure that would apply to every network without understanding the operational issues particular to that network and the embedded entry points' operational requirements and control modes, see Section 9 for further detail.

It is recommended that models of several other networks with embedded entries (biomethane and potential hydrogen blend) be investigated to assess whether a robust Charging Area could be defined using Option 1 Pragmatic; annual use analysis or the alternative Pragmatic approaches discussed in Appendix D . Aspects that should be considered include but are not limited to the following:

- Stability / variability of embedded gas entry point supplies,
- Proximity of large and very large users to the embedded supply,
- Sensitivity analysis of input parameters to Charging Area boundary definition,
- Appropriate frequency of billing zone determination and update,
- A review of non-domestic energy profiles used in network modelling,
- The potential for the development of an automated system for aspects of the network analysis.
- Default and correction mechanisms for new sites or unforeseen changes in network flows.

It is recognised that in certain instances if the CV impacted Charging Area is not relatively static or easy to define, the Pragmatic approach may not be suitable for a selected embedded entry. However, the application of Option 1 Pragmatic should be further investigated for feasibility, considering factors listed above, as this approach could fulfil a transitional role and may bring earlier benefits for some embedded renewable-source gas supplies, while a full end-to-end essential system architecture solution is developed for a future billing methodology.

As a development of the Pragmatic Option 1 it could be possible to identify areas of an LDZ that have a single source of supply (from an NTS offtake, or IP PRS etc) where all downstream consumers receive gas from that single point. If a new CV measurement device (and flow measurement if required) was to be installed at that point, all downstream consumers could be billed on the CV of gas delivered through that facility rather than the overall LDZ FWACV as now. This would identify parts of the LDZ network that could be created as separate Charging Areas. To facilitate this, it is recommended that the Gas (Calculation of Thermal Energy) Regulations be reviewed to better understand the potential for the use of within-network CV measurement.

In assessing the feasibility of Composite Option 2, at this stage there is no recommendation that Charging Areas be developed around each offtake from the NTS. Some Offtakes could be suitable (i.e., feeding a single pipeline as described above) but the majority feed into LTS networks where there is dynamic interaction with other offtakes i.e., changes in offtake flow for network management and operational reasons rather than just demand, use of the system for linepack etc. Further network specific understanding and complex modelling work would be required to evaluate and assess Charging Areas development.

In assessing the feasibility of Option 3 Ideal reference should be made to the key findings from the MS11 Smart Metering Laboratory Trials Report. There are a number of technical challenges/limitations including, though not limited to, meter battery life, data reading traffic load and metering specifications for kWh retrieval, requiring further exploration and understanding. Potentially this option may not be workable within the timeframe given the requirement to also consider the implications of a future move to Hydrogen, which would involve the roll-out of hydrogen-specific meters.

For both Option 2 Composite and Option 3 Ideal, the installation of large numbers of CV measurement devices within GB gas networks would be required and this is not a sustainable solution due to the factors identified in Table 13, namely overall cost and emissions from venting.

No advances in technology to overcomes these factors have been forthcoming during the project timeframe. Advances in gas analytics technology are being trialled as part of the separate HyDeploy2 project and other similar products may exist elsewhere. It is recommended that submissions be actively sought for the development of CV measurement devices which are sufficiently accurate, compact, environmentally sustainable and energy-efficient. These could bring significant benefits to the gas industry's transition to net zero.

In assessing the feasibility of Option 4 Modelled CV consideration should include, but not be limited to the following (not listed in any order of significance):

- A review, and potential update, of the Gas (Calculation of Thermal Energy) Regulations to determine whether they could accommodate the use of a modelled CV for billing purposes.
- The application and benefits of online LTS modelling to inform CV at LTS offtakes into the pressure-controlled tiers of the LDZ pipeline system.
- Potential for and benefits of integration of downstream network models for IP, MP and LP systems.
- Identify all critical data items and feeds into the network modelling process and assessing opportunities to streamline data feed processes and maintain data integrity.
- Determining the appropriate frequency, timing and potential for automation of network modelling processes to achieve the correct balance between accuracy and practicality of process, to remain within existing limits on cross-subsidy between consumers.

Additional considerations

The output from the Real Time Network demand modelling project has provided SGN and the industry with an improved understanding of demands in line with the latest appliances and consumer behaviour. If this learning were to be implemented by the industry, this would impact on all current and future network analysis activities. This updated understanding of demands could improve the modelling results undertaken for any of the FBM options as all rely on network modelling.

With the proposed use of network models for consumer billing (either for the allocation of a SMP to a Charging Area or the generation of a modelled CV), the appropriate modelling of consumer demand is key. In addition to the learning from the RTN project, it is understood there is more detailed gas demand data which if readily available to the DNs, would support the use of modelling for billing purposes. It is recommended that this is explored through the industry consultation.

Along with the Xoserve system architecture changes, the requirements for the following should be considered:

- creation of the appropriate interface with Xoserve systems;
- development of the necessary changes to UK-Link billing processes;
- establishing and maintaining critical System User requirements for billing.

It is also recommended that the industry consultation invites and gathers industry feedback to identify aspects or concerns that may not have been considered in this study.

Following industry consultation, it is recommended the Charging Area process that is taken forward is documented as an industry procedure to be followed to ensure consistency of approach for all consumers.

Post implementation, it is recommended that temporary CV measurements are taken at points in the network to verify the Charging Area values to help maintain levels of customer protection.

APPENDIX A LIST OF TERMS

Term	Meaning
CBA	Cost-Benefit Analysis
CV	Calorific Value – expressed in mega Joules per cubic metre of gas (MJ/m^3) at standard temperature and pressure
CVDD	CV Determination Device
DNV GL	Project partner of Cadent now known as DNV
EA	The LDZ known as East Anglia
EM	The LDZ known as East Midlands
FBM	Future Billing Methodology
FWACV	Flow Weighted Average Calorific Value
GB	Great Britain
GDN	Gas Distribution Network
GS(M)R	Gas Safety (Management) Regulations – governs the safety of the GB gas supply
IGEM	Institute of Gas Engineers and Managers
IP	Intermediate Pressure
kscmd	Thousands of standard cubic meters per day
LDZ	Local Distribution Zone (gas distribution networks in GB comprise 13 LDZs)
LP	Low Pressure
LTS	Local Transmission System
MP	Medium Pressure
NIC	Network Innovation Competition
scmh	Standard cubic meters per hour
SMP	Supply Meter Point

APPENDIX B FINAL INSTALLED SENSOR LOCATION LIST

B.1 Cambridge Network

Site ID	Site Name
FBM01	Cottenham Village
FBM02	Home Close, Histon
FBM03	Homefield Park
FBM06	Recreation Ground, Girton CB3 0FH
FBM10	Hills Road, Cambridge CB1 7RU
FBM11	Perne Road, Cambridge CB1 3RU
FBM12	Langdale Close, Cambridge CB1 9LP
FBM16	Grange Road Cambridge CB3 9DB
FBM42	North end of Histon Rd, Cottenham
FBM43	Orchard Rd/Mill Ln, Impington
FBM44	Cottenham Rd/Glebe Way, Impington
FBM45	South end of Home Close, Impington
FBM46	Villa Rd, Impington
FBM47	Huntington Rd (A1307) near Lawrence Weaver Rd
FBM49	Gilbert Rd - Near Milton Rd
FBM50	Wynford Way - Close to Crathern Way
FBM51	Woodhead Dr - Close to Robert Jennings Close
FBM52	Gresham Rd - Close to Harvey Rd
FBM53	Young Street
FBM54	Fanshawe Rd - Close to Sterne Close
FBM55	Cambridge Road - Close to Walden Way

B.2 Lincolnshire Network

Site ID	Site Name
FBM19	Scotter Gravel Pit Rd
FBM21	East Gate Scotton
FBM22	Grove St Kirton Lindsey
FBM23	Redbourne Rd
FBM24	Ings Street and Church Street
FBM25	Gainsborough Lane
FBM26	Messingham Lane
FBM27	Brigg Barnard Ave
FBM30	North Kelsey Rd Caistor
FBM31	Laceby Grimsby Rd
FBM35	Louth Rd
FBM36	Market Rasen Chapel St
FBM38	Louth Albion Place

APPENDIX C SENSOR DATA APPLICATION IN NETWORK MODELLING

C.1 Cambridge Network

Data Item	Data Source	Logger/Node	Data Application	
			Modelling Parameter	Modelling Comparison
Oxygen value	FBM Oxygen Sensor	FBM01-16		Synergi reference profile
Oxygen value	FBM Oxygen Sensor	FBM42-55		Synergi reference profile
Oxygen value	FBM Oxygen Sensor	CHITRING		Synergi reference profile
Pressure	Cadent	FBM01-16	Synergi regulator station set outlet pressure	
Pressure	FBM	FBM01-16		Synergi pressure profile
Pressure	FBM	FBM42-55		Synergi pressure profile
Pressure	Cadent	BALSHAM	Synergi source regulator set pressure profile	
Pressure	Cadent	GIRTON	Synergi source regulator set pressure profile	
Pressure	Cadent	MDNGLYRD	Synergi source regulator set pressure profile	
Pressure	Cadent	TEVRSHAM	Synergi source regulator set pressure profile	
Pressure	Cadent	ROYSTON	Synergi source regulator set pressure profile	
Pressure	Cadent	CAMBRDG	Synergi regulator station set pressure profile	
Pressure	Cadent	CHITRING		Synergi source reference pressure profile
Pressure	Cadent	10320 DRYDRAYTON	Synergi network regulator set pressure profile	
Pressure	Cadent	12412 FULBOURN	Synergi network regulator set pressure profile	
Pressure	Cadent	17031 MDNGLYRD	Synergi network regulator set pressure profile	
Pressure	Cadent	50029 ARBURYRD	Synergi network regulator station set pressure profile	
Pressure	Cadent	12123 NEWHALL	Synergi network regulator station set pressure profile	
Pressure	Cadent	12124 FBM16 GRANGERD KINGSRD	Synergi network regulator station set pressure profile	
Flow	FBM	FBM01-16		Synergi flow profile
Flow	FBM	BALSHAM		Synergi flow profile
Flow	FBM	GIRTON		Synergi flow profile
Flow	FBM	MDNGLYRD		Synergi flow profile
Flow	FBM	TEVRSHAM		Synergi flow profile
Flow	FBM	ROYSTON		Synergi flow profile
Flow	FBM	CHITRING	Synergi source flow profile	
CV	FBM Gas PT	FBM6, 12		Synergi reference profile
CV	FBM	CHITRING		Synergi reference profile
CV	FBM	ROYSTON		Synergi reference profile

Yearly Flow Profiles	DNV GL	All demands	Seasonal scaling of Pk6 demand according to demand type	
Weekly Flow Profile	DNV GL	Yearly flow profile	Diurnal scaling of Pk6 demand	

C.2 Lincolnshire Network

Data Item	Data Source	Logger/Node	Data Application	
			Modelling Parameter	Modelling Comparison
Oxygen value	FBM Oxygen Sensor	FBM19-38		GBNA visual reference for biomethane
Pressure	FBM	FBM19-38		GBNA reference pressure
Pressure	Cadent	Selected sources	GBNA source pressure	
Flow	FBM	FBM19-38		GBNA reference flow
Flow	FBM	Hibaldstow	GBNA source flow	
Yearly Flow Profile	DNV GL	All demands	Weekday/weekend Maxfit scaling	

APPENDIX D ALTERNATIVE APPROACHES FOR THE PRAGMATIC OPTION

D.1 Pragmatic Option - Identify Different-CV Charging Area using CV Modelling

Use CV modelling to predict the extent of a ‘different-CV’ gas under one or a number of scenarios, for example:

- Full extent of a low-CV gas at the minimum demand and / or maximum supply
- Full extent of a low-CV gas at the average demand and / or average supply
- Full extent of a low-CV gas at the maximum demand and / or minimum supply

All SMPs within the identified ‘different-CV’ Charging Area would be assigned to the different-CV gas source CVDD, while all others would be billed on the LDZ FWACV. This method of defining Charging Areas around existing embedded inputs, such as biomethane entry points, is in the manner envisaged by the original FBM Pragmatic option. This method can be equally applied to low and high CV embedded entry points. It is a method that works well for a network where an embedded entry is pressure controlled rather than flow controlled and is summarised below in Figure 67.

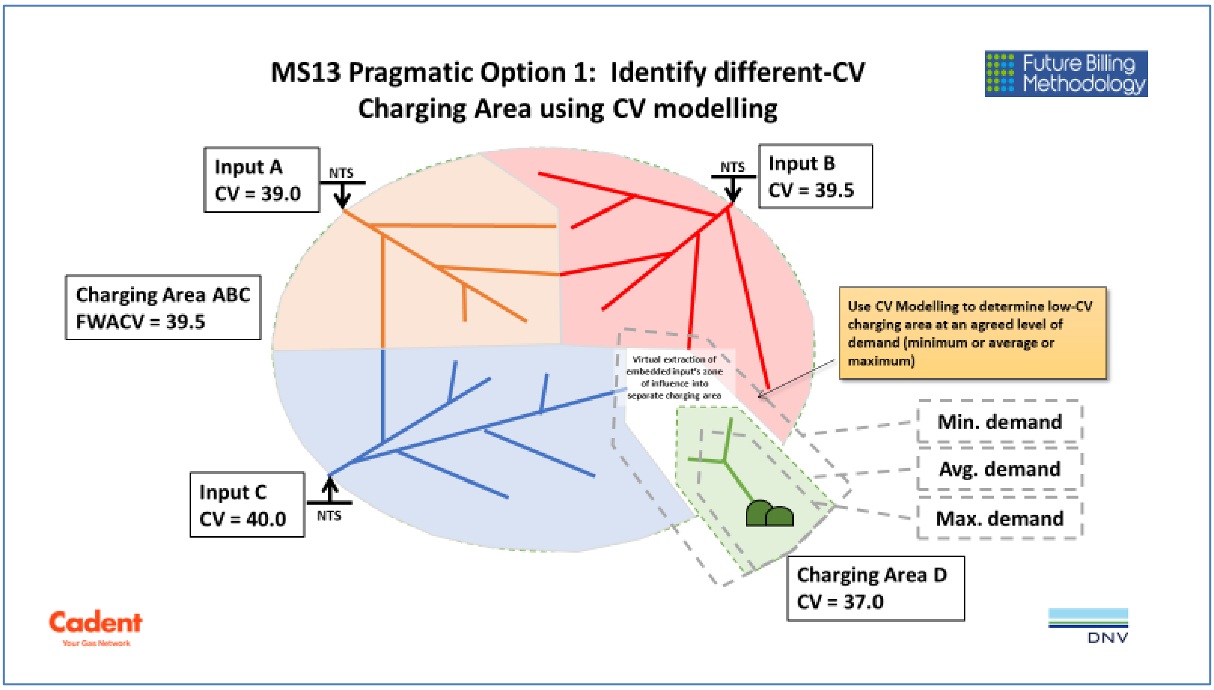

Figure 67 – Pragmatic Option 1 – Identify Different-CV Charging Area using CV Modelling

Worked example

As a simple example, Figure 68 shows possible Charging Areas for the biomethane entry at Chittering, with the areas for 3 different demand conditions; the lower the demand the further the Charging Area extends. If a high demand condition is used to define the Charging Area then all SMPs north of the ‘zone 1 (high demand)’ line would be assigned to the embedded entry CVDD for billing purposes and all other SMPs on the network would be billed on the LDZ FWACV. In practice, there would only be one Charging Area based upon a pre-determined / agreed demand level. In addition, a CV value to be used in the boundary definition needs to be pre-determined / agreed. For example, if the ‘different’ CV gas entering the network is 37 MJ/m^3 is the boundary at 37 MJ/m^3 or 38 MJ/m^3, or another value? All three zones depicted here are based on boundary of up to 38 MJ/m^3 (i.e., 1 MJ/m^3 above the 'different' gas) so the impact of an SMPs Charging Area allocation can be understood.

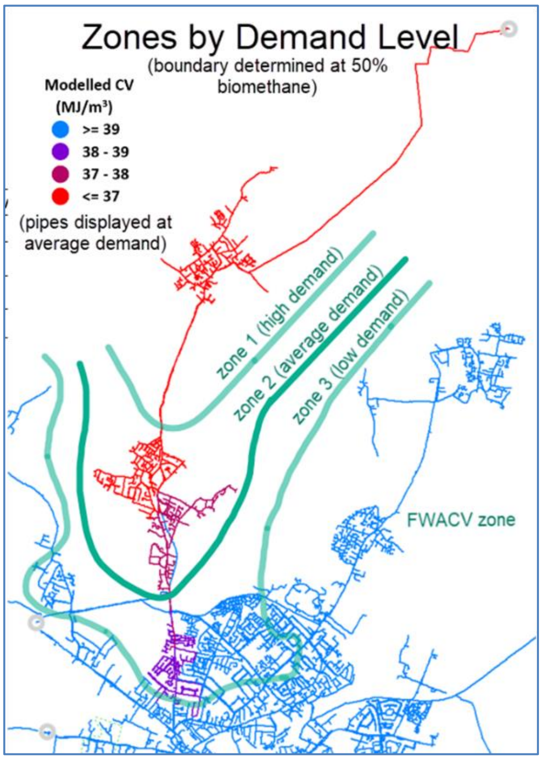

Figure 68 – Example of Possible Low-CV Charging Areas – Pipes Coloured at an Average Demand Condition

In Figure 68 the pipes are coloured to indicate the modelled CV of the gas in the pipes at an average demand condition. The 3 zone boundaries indicate where the modelled CV of up to 38 MJ/m^3 extends under the 3 different demand conditions.

Table 14 below shows the financial impact that the Charging Area allocation has on a consumers bill depending upon what demand condition is used to define the boundary and therefore whether a consumer is allocated the embedded entry gas CV or FWACV for billing purposes .

			Zone 1 Charging Area High demand			Zone 2 Charging Area Average demand			Zone 3 Charging Area Low demand		
		Energy Actual Cost[16]	Billed on Embedded = 37 MJ/m^3 FWACV 39.1			Billed on Embedded = 37 MJ/m^3 FWACV 39.1			Billed on Embedded = 37 MJ/m^3 FWACV 39.1		
	Zone		Bill	£ diff	% diff	Bill	£ diff	% diff	Bill	£ diff	% diff
FBM42	1	£610.56	£610.56	£0.00	0%	£610.56	£0.00	0%	£610.56	£0.00	0%
FBM43	2	£610.56	£613.20	£2.65	0.43%	£580.27	-£30.29	-4.96%	£580.27	-£30.29	-4.96%
FBM44	2	£610.56	£612.97	£2.41	0.39%	£580.05	-£30.51	-5.00%	£580.05	-£30.51	-5.00%
FBM45	2	£610.56	£612.23	£1.67	0.27%	£579.35	-£31.21	-5.11%	£579.35	-£31.21	-5.11%
FBM46	2	£610.56	£611.86	£1.30	0.21%	£578.99	-£31.56	-5.17%	£578.99	-£31.56	-5.17%
FBM47	FWACV	£610.56	£610.71	£0.15	0.02%	£610.71	£0.15	0.02%	£610.71	£0.15	0.02%
FBM50	3	£610.56	£610.56	£0.00	0.00%	£610.86	£0.30	0.05%	£578.05	-£32.51	-5.32%
FBM51	3	£610.56	£610.56	£0.00	0.00%	£610.69	£0.13	0.02%	£577.89	-£32.67	-5.35%
FBM52	FWACV	£610.56	£610.56	£0.00	0.00%	£610.49	-£0.07	-0.01%	£610.49	-£0.07	-0.01%
FBM54	FWACV	£610.56	£610.48	-£0.08	-0.01%	£610.48	-£0.08	-0.01%	£610.48	-£0.08	-0.01%
FBM55	FWACV	£610.56	£610.42	-£0.14	-0.02%	£610.42	-£0.14	-0.02%	£610.42	-£0.14	-0.02%

Table 14 – Example Low CV Charging Area Determined at Three Different Demand Condition Impact on Bills

Reading from the table, for a consumer at FBM44, the annual bill differences depending upon the demand condition used to allocate the SMP to a Charging Area are:

- £612.97, slightly overpaying £2.41 if Zone 1 Charging Area is chosen,
- £580.05, underpaying by £30.51 if Zone 2 Charging Area is chosen
- £580.05, underpaying by £30.51 if Zone 3 Charging Area is chosen

In this example, as the level of demand used in the modelling reduces, so too does the inequality in consumer bills based on their upfront allocation to a Charging Area. In practice only one demand level would be analysed to allocate a consumer to a Charging Area.

With any approach where a SMP is assigned to a CVDD there is a risk of misallocation whereby a consumer could be wrongly assigned to the FWACV but receive more gas from a low CV embedded entry and be over billed for their energy use. Undertaking analysis at a lower demand level (to be agreed, see section 9.2), i.e., a ‘wider zone approach’ would provide an increased level of protection to all consumers from overbilling.

[16] The worked examples have assumed each consumer has the same annual gas energy requirement. The example cost is calculated based on a modelled CV of gas received at each location. The “Energy Actual Cost” is the same for consumers at each location (i.e., higher CV = lower metered volume); this represents what the customer should be billed if energy attribution to metered gas flows was perfect

D.2 Pragmatic Option - Identify Charging Areas by CV Bands

Use CV modelling to predict the network analysis model system nodes on the network receiving gas with a CV more than 1 MJ/m3 below the flow-weighted average CV for the “non-low-CV” LDZ input points, stratifying in bands of 1 MJ/m3. All SMPs within the network would be assigned a billing CV based on the modelled values and their relationship to the LDZ FWACV. This method of defining Charging Areas across a network is a development of Option A above with 1 MJ/m^3 bands, an extension of that envisaged by the original FBM Pragmatic option. This method can be equally applied to a high CV embedded entry and is summarised below in Figure 69.

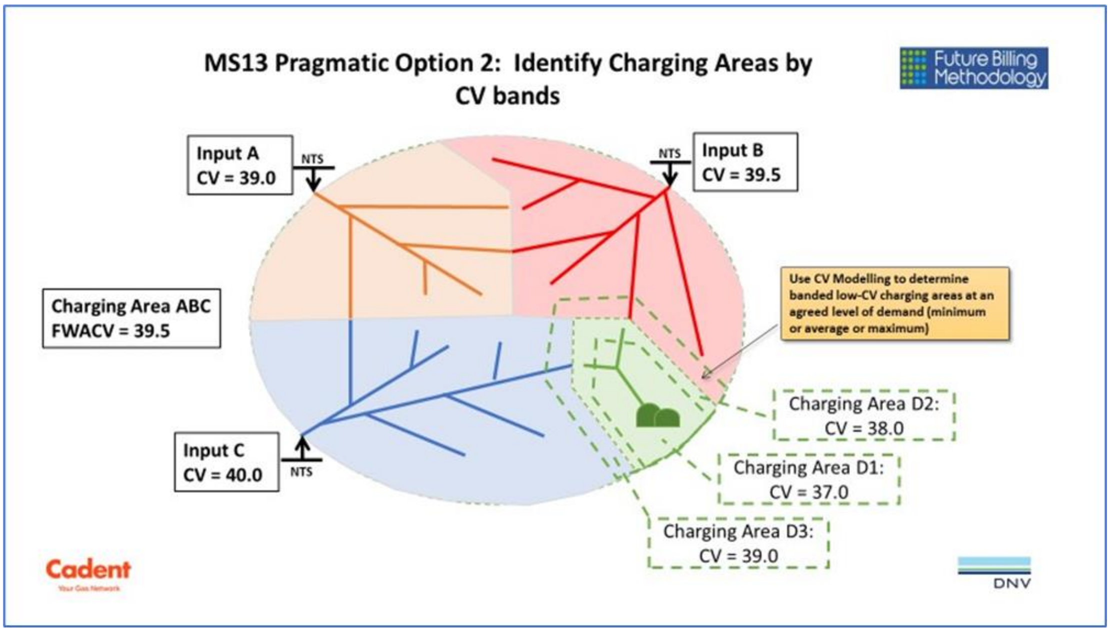

Figure 69 – Pragmatic Option 2 – Identify Charging Areas by CV Bands

Worked Example

As a simple example, Figure 70 shows possible Charging Areas for the biomethane entry at Chittering, with the areas for CV bands based upon a pre-determined / agreed demand level. In this example there are 4 charging bands based on the CVs delivered to the network at an average demand condition.

Using the network modelling the SMPs would be assigned to the various bands as individual Charging Areas. SMPs receiving the low CV gas at 37 MJ/m^3 (supplied by the pipes coloured in red) would be assigned to the low-CV CVDD for their billing CV. Those SMPs that fall into the bands either side of the embedded entry CV and the FWACV would be assigned a billing CV in relation to the FWACV, for example 1 MJ/m^3 less than the FWACV, 2 MJ/m^3 less than the FWACV. The remaining SMPs would be assigned to the FWACV. This method applies the principles of the existing 1 MJ/m^3 tolerance within the current FWACV capping regime.

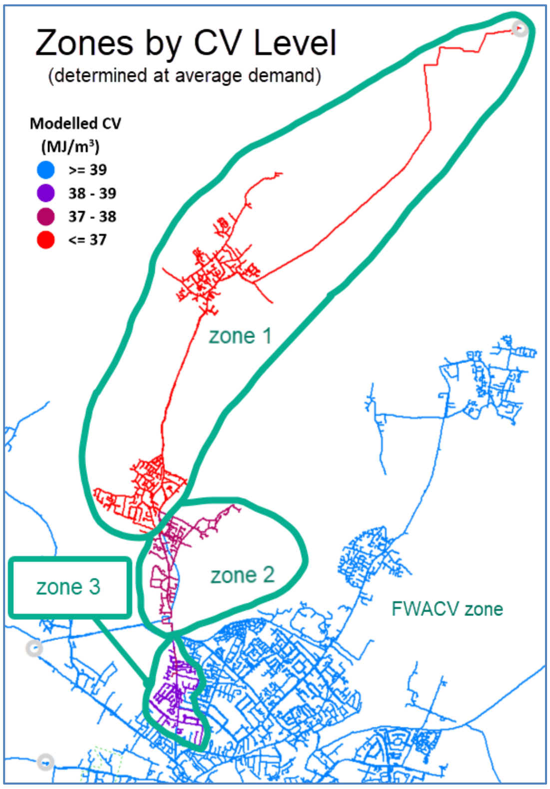

Figure 70 – Example of 1 MJ/m^3 stratified Charging Areas

Below shows the financial impact that the Charging Area allocation has on a consumers bill depending upon what CV band a consumer falls into.

		Billed on Embedded = 37 MJ/m^3 FWACV 39.1		
	Zone	Bill	£ diff	% diff
FBM42	1	610.56	0.00	0%
FBM43	1	580.27	-30.29	-5%
FBM44	1	580.05	-30.51	-5%
FBM45	1	579.35	-31.21	-5%
FBM46	2	587.21	-23.35	-4%
FBM47	FWACV	610.71	0.15	0%
FBM50	FWACV	610.86	0.30	0%
FBM51	FWACV	610.69	0.13	0%
FBM52	FWACV	610.49	-0.07	0%
FBM54	FWACV	610.48	-0.08	0%
FBM55	FWACV	610.42	-0.14	0%

Table 15 – Example of CV Bands Charging Area Impact on Bills

For example, for a consumer at FBM44, their billing CV would be the embedded entry CV and as a consequence would pay an annual bill of £580.05, underpaying by £30.51.

A different pre-determined / agreed demand level could generate different banding therefore different Charging Area allocation. An alternative basis for the CV billing bands could be to work upwards from a low-CV input, but this too would result in inequality in consumer bills based on their upfront allocation to a Charging Area.

D.3 Pros and Cons of all options considered

Below is a table of the methods, the 4 options in the main body of the reports, alongside those described above, summarising the pros and cons to aid industry consultation on the way forward. It has been assumed that system architecture, Network Code changes, system requirements by Xoserve, Shippers and Suppliers etc is the same for each option so related Pros and Cons have not been included in the table.

	Measured CVs used for Consumer Billing					Modelled CVs used for Consumer Billing 4- Modelled CV for Billing using Online LTS model	
	1A - Different CV Charging Area	1B - Charging Areas by CV bands	1C - Annual Use Analysis	2 - NIC Composite	3 - NIC Ideal	Before the Day	After the Day
Pros	Simple steady state network modelling of a single demand condition	Simple steady state network modelling of a single demand condition	Multiple Steady State network analysis modelling including the application of an annual profile of demand rather than a single demand condition and accounting for within year planned operational settings	Network analysis would model the CVs through the pressure tiers	Limited network analysis required	Use of online modelling to determine a CV at the LTS exit points; a continually updated value	Reconstruction of the network state after the day to generate the CV received at the SMP
	Upfront analysis of the network models	Upfront analysis of the network models	Upfront analysis of the network models	Upfront analysis of the network models	Upfront analysis of the network models	Upfront analysis of the below LTS network models	
	Applicable to low and high CV embedded entry and H2 blends	Applicable to low and high CV embedded entry and H2 blends	Applicable to low and high CV embedded entry and H2 blends	Applicable to low and high CV embedded entry and H2 blends	Applicable to low and high CV embedded entry and H2 blends	Applicable to low and high CV embedded entry and H2 blends	Applicable to low and high CV embedded entry and H2 blends
	Fixed allocation of SMP to Charging Area; annual or periodic re-assessment of Charging Areas	Fixed allocation of SMP to Charging Area; annual or periodic re-assessment of Charging Areas	Fixed allocation of SMP to Charging Area; annual or periodic re-assessment of Charging Areas	Fixed allocation of SMP to Charging Area; annual or periodic re-assessment of Charging Areas	Most equitable approach for Consumer billing as the CV is measured close to the point of use	Fixed allocation of SMP to Charging Area; annual or periodic re-assessment of Charging Areas	Most equitable approach for Consumer billing as the CV is modelled close to the point of use
	Can be undertaken with existing modelling software	Can be undertaken with existing modelling software	Can be undertaken with existing modelling software	Can be undertaken with existing modelling software	Can be undertaken with existing modelling software		
	Consumer Billing CV is from a measured CVDD	Consumer Billing CV is from a measured CVDD	Consumer Billing CV is from a measured CVDD	Consumer Billing CV is from a measured CVDD closer to the point of use	Consumer Billing CV is from a local measured CVDD very close to the point of use	Consumer Billing CV is from a modelled value closer to the point of use	Consumer Billing CV is from a local modelled value very close to the point of use
			Charging Area determined by the financial analysis of the impact on consumers; variation of predicted annual modelled CV and annual consumer energy use profile. This method could be more equitable for the consumer bill compared to alternatives considered in 1A and 1B			Measured CVs used to generate a billing CV based upon continually updated online LTS modelling	Measured CVs used to generate a billing CV based upon continually updated online LTS modelling

	Measured CVs used for Consumer Billing					Modelled CVs used for Consumer Billing 4- Modelled CV for Billing using Online LTS model	
	1A - Different CV Charging Area	1B - Charging Areas by CV bands	1C - Annual Use Analysis	2 - NIC Composite	3 - NIC Ideal	Before the Day	After the Day
Pros						Modelled CV to be used for billing is cheaper and 'greener' than the installation of a number of physical CVDDs (currently available)	Modelled CV to be used for billing is cheaper and 'greener' than the installation of a number of physical CVDDs (currently available)
						Consistent platform for handling the full transition to gas decarbonisation	Consistent platform for handling the full transition to gas decarbonisation
						Existing commonality of node names on LTS and Gemini system	Existing commonality of node names on LTS and Gemini system
Cons	Fixed Charging Area that assumes minimal changes in network / demand dynamics	Fixed Charging Area that assumes minimal changes in network / demand dynamics	Fixed Charging Area that assumes minimal changes in network / demand dynamics	Fixed Charging Area that assumes minimal changes in network / demand dynamics		Fixed Charging Area that assumes minimal changes in network / demand dynamics	
	Limited equitability based on a single or fixed demand level	Limited equitability based on a single or fixed demand level					
	Risk that variations in input CV and network state may not have been considered when the Charging Area is created	Risk that variations in input CV and network state may not have been considered when the Charging Area is created	Risk that variations in input CV and network state may not have been considered when the Charging Area is created	The variable network state on the LTS is not taken into account when the Charging Area is created		The variable network state on the LTS is not taken into account when the Charging Area is created	
	Requires annual network demand profiles and energy use profiles for different consumer types	Requires annual network demand profiles and energy use profiles for different consumer types	Requires annual network demand profiles and energy use profiles for different consumer types	Requires a decision on the approach for upfront offline modelling to define Charging Areas below the LTS		Requires a decision on the approach for upfront offline modelling to define Charging Areas below the LTS	
	Requires modelling to create CV Charging Area	Requires modelling to create CV bands	Requires modelling to create CV Charging Area	Requires modelling to create CV Charging Area		Requires modelling to create CV Charging Area	Requires modelling to create CV Charging Area

	Measured CVs used for Consumer Billing					Modelled CVs used for Consumer Billing 4- Modelled CV for Billing using Online LTS model	
	1A - Different CV Charging Area	1B - Charging Areas by CV bands	1C - Annual Use Analysis	2 - NIC Composite	3 - NIC Ideal	Before the Day	After the Day
Cons			Additional network analysis required compared to methods 1A and 1B to generate Charging Area; could be mitigated through some automation	Additional network analysis required from NTS offtake down through the pressure tiers as well as steady state modelling of the lower pressure tiers		Additional network analysis required from NTS offtake down through the pressure tiers as well as steady state modelling of the lower pressure tiers	Complex network modelling to recreate the LDZ network-state after the day to generate the billing CV by network node / SMP
				Cost of installation, powering and maintenance of ~10,000 additional CVDD equipment units	Cost of installation, powering and maintenance of ~44,000 additional CVDD equipment units		
				Assuming current technology - emissions from additional CVDD venting up to 130 ktCO2e; CoC ~£9.2m per year.	Assuming current technology - emissions from additional CVDD venting up to 580 ktCO2e; CoC ~£40.6m per year.		
					Technical challenges/limitations of assigning a CV to a smart meter		
						Requires the implementation of suitable LTS online software	Requires the implementation of suitable LTS online software
						Consumer Billing CV is not from a measured CVDD	Consumer Billing CV is not from a measured CVDD
							Highly system intensive
							Significant amount of network related data required to recreate the LDZ network-state on a daily basis

	Measured CVs used for Consumer Billing					Modelled CVs used for Consumer Billing 4- Modelled CV for Billing using Online LTS model	
	1A - Different CV Charging Area	1B - Charging Areas by CV bands	1C - Annual Use Analysis	2 - NIC Composite	3 - NIC Ideal	Before the Day	After the Day
CAPEX	£58.0m	£58.0m	£58.0m	£393.9m	£799.1m	£81.3m	£81.3m
OPEX (Set-up) £m	£0.3m	£0.3m	£0.3m	£1.2m	£3.12m	£1.2m	£3.3m
OPEX (On-going) £m	£2.4m	£2.4m	£2.4m	£6.9m	£12.8m	£4.5m	£5.3m

Table 16 – Pros and Cons of FBM Options, including Alternatives for Pragmatic

APPENDIX E OXYGEN RECORDINGS

E.1 Oxygen Recordings Description Overview

To further interrogate the data and provide a view of the spread of the biomethane gas over a longer time frame and the frequency with which this gas was seen across the network, the data has been presented in a 'stacked' view. This gives a concurrent view of each of the oxygen measurements (up to the upper limit of 200ppm) at the sensor locations.

In the subsequent figures, the average daily oxygen measurements at each sensor location have been stacked on top of each other for a particular time period. The individual sensor locations are shown as a colour block and are presented, from the bottom to the top of the chart, in distance from the biomethane entry point; the x-axis on the left-hand side is the sum of the individual oxygen measurements. In addition, the data also has the biomethane entry volume of flow, with the relevant axis [(Chittring Flow (Daily Sum)] on the right-hand side.

When the coloured blocks are greater in number and / or taller in size and contributing to a greater overall stack height, this demonstrates that the biomethane has travelled further into the network. When the coloured blocks are fewer in number and / or smaller in size contributing to a lower overall stack height, this demonstrates that the biomethane has been consumed closer to the embedded entry point.

Where there is an individual coloured block smaller in height than the 200 block, this represents an oxygen reading of less than 200 ppm at that location indicating the sensor is recording gas that is definitely a blend of biomethane and NTS gas, for example FBM47.

Note:

1. Reference should be made to the tables in Section 3.4 because if a sensor is not reading it will not appear in the stacked view and could be mis-interpreted as a 'zero' ppm read.
2. The x-axis refers to the sum of the ppm of all the sensors that are recording. As the number of sensors changes, as does the scale of the axis; comparing the height of two graphs without reference to the x-axis scale could be misleading.

E.2 Oxygen Recordings for Cambridge Within Street Sensors

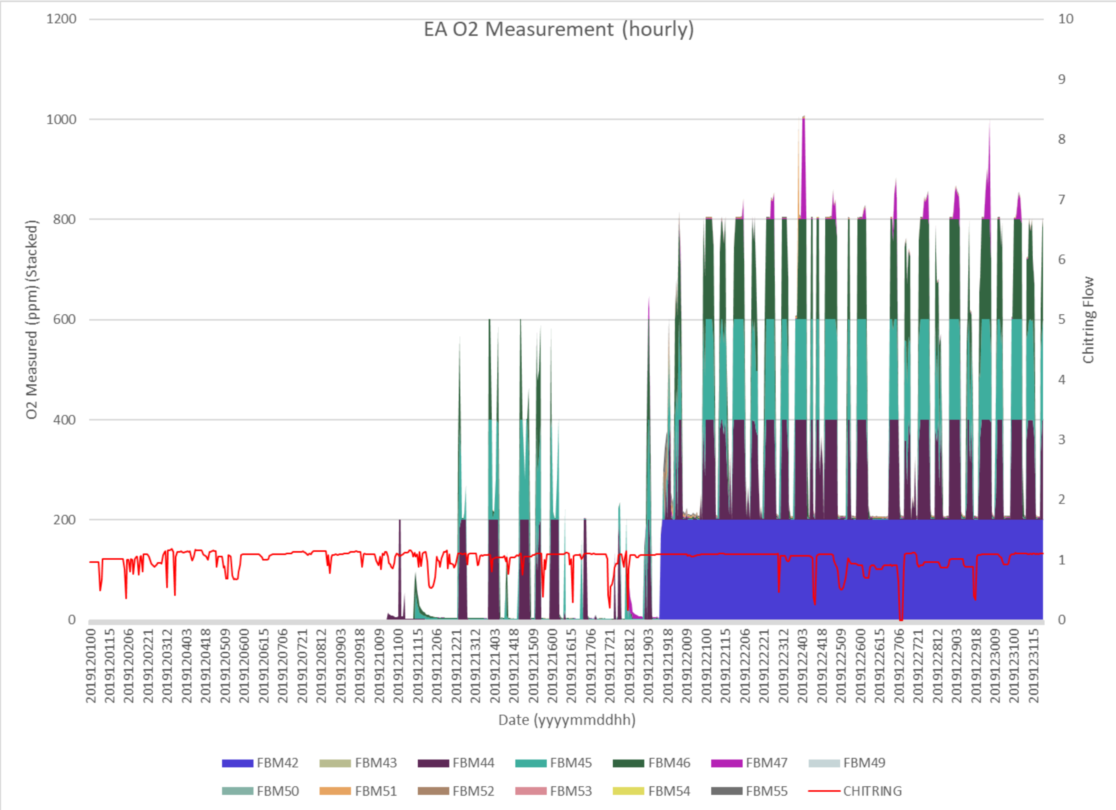

Figure 71 – December 2019

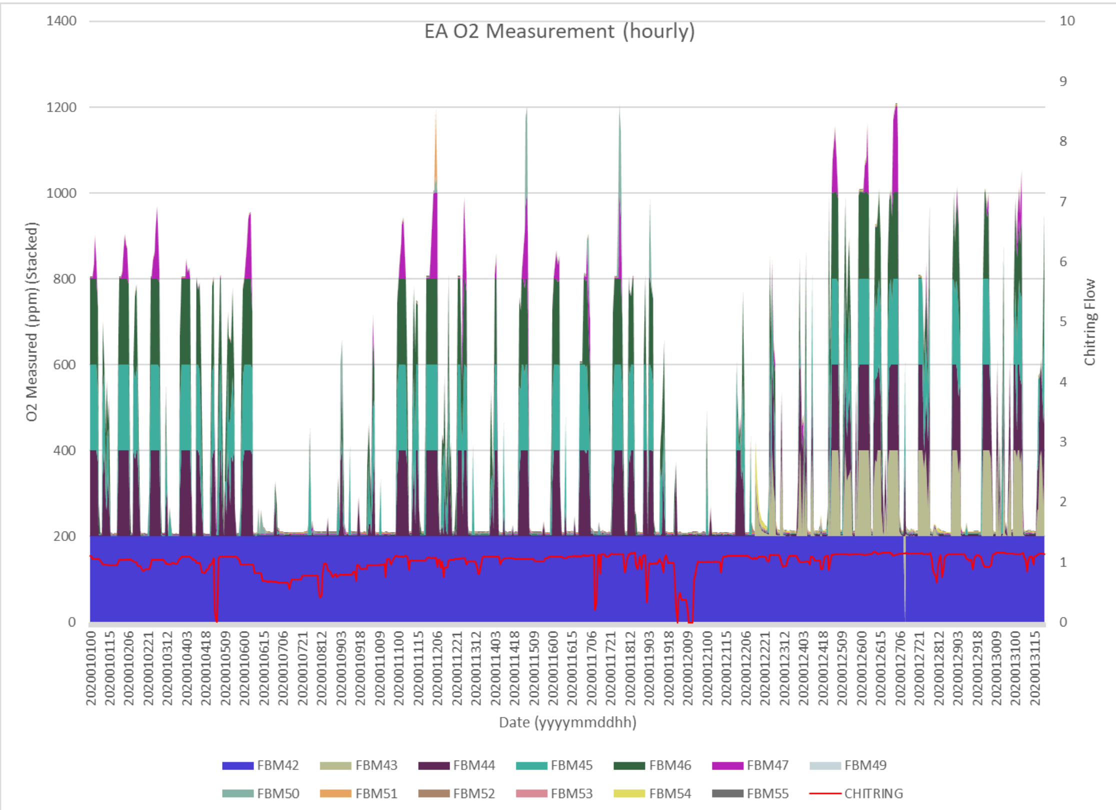

Figure 72 – January 2020

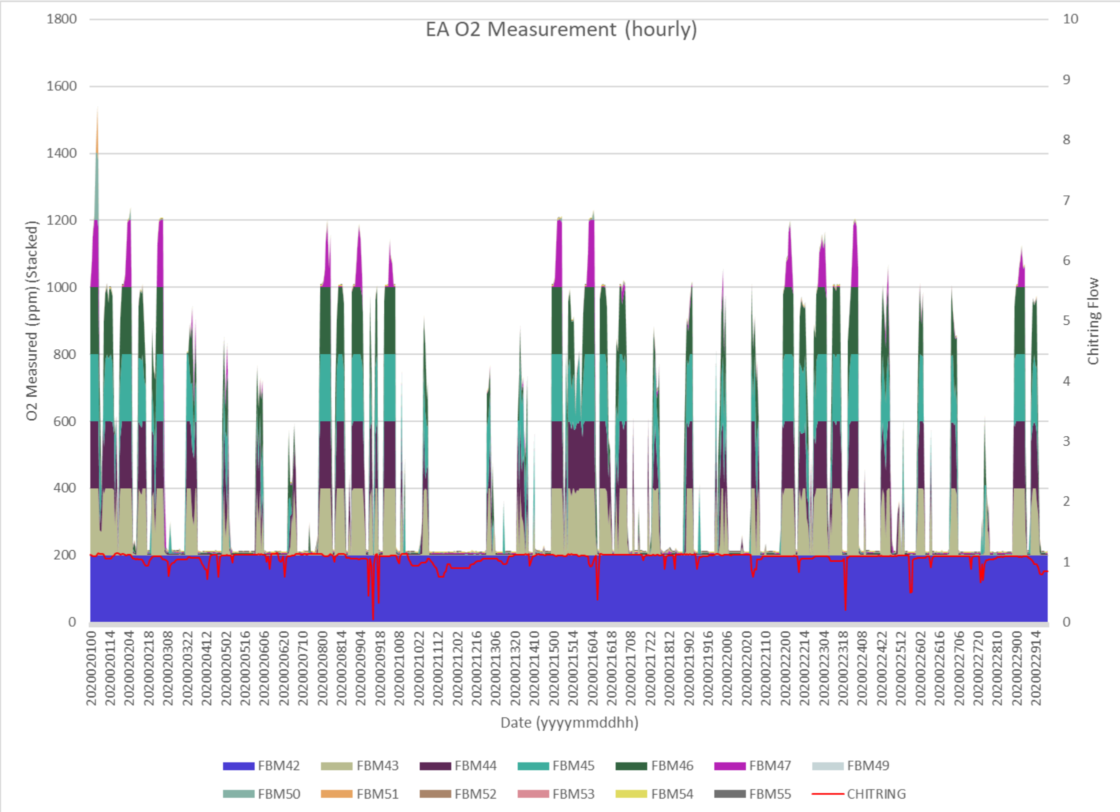

Figure 73 – February 2020

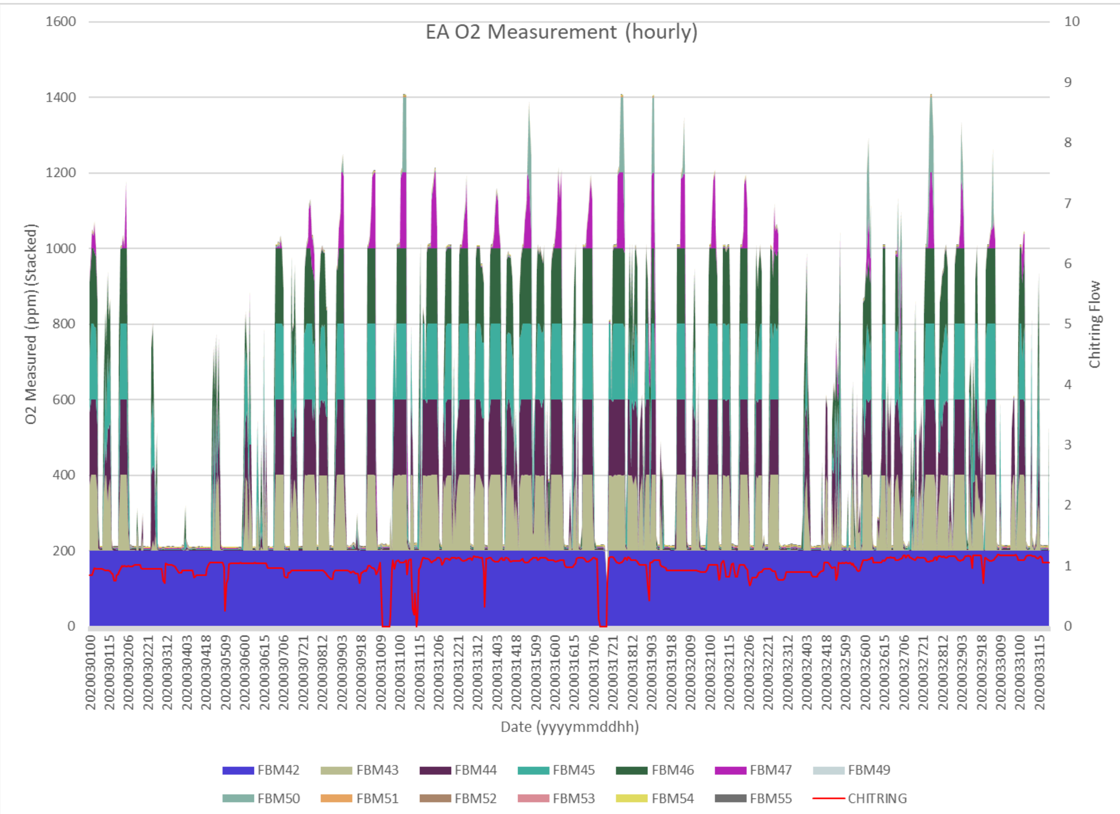

Figure 74 – March 2020

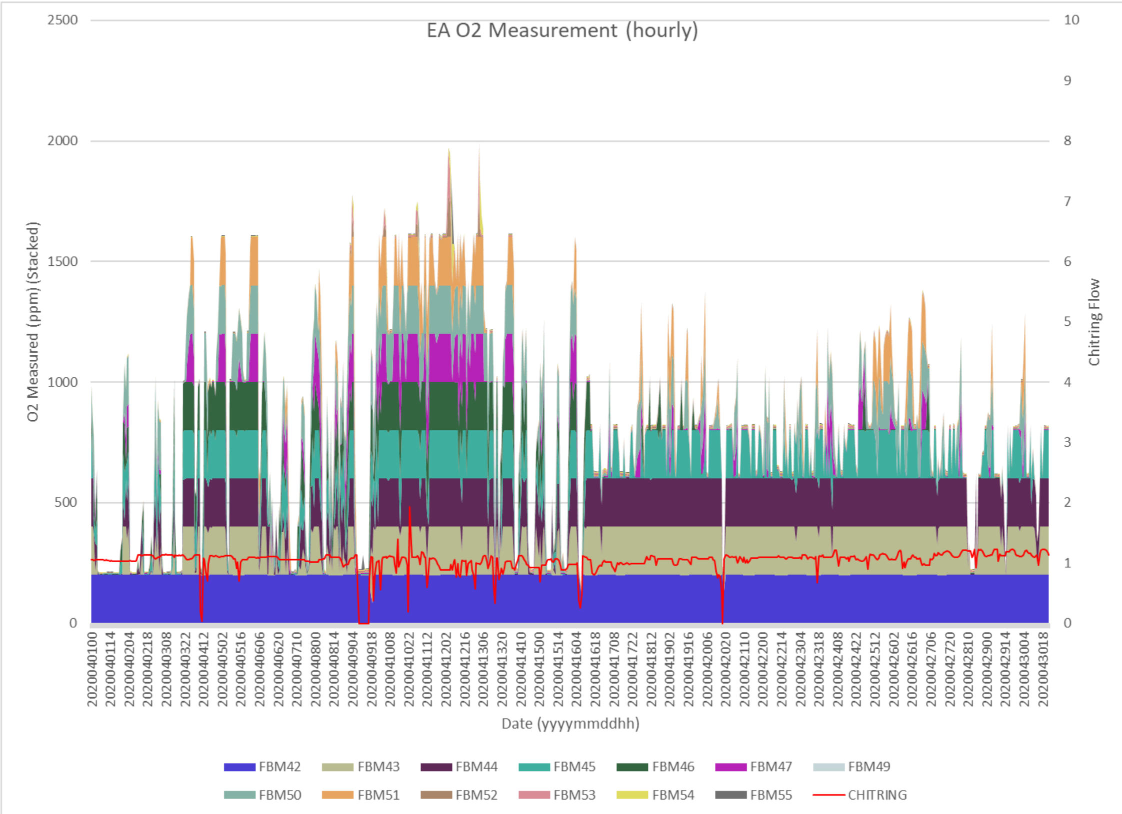

Figure 75 – April 2020

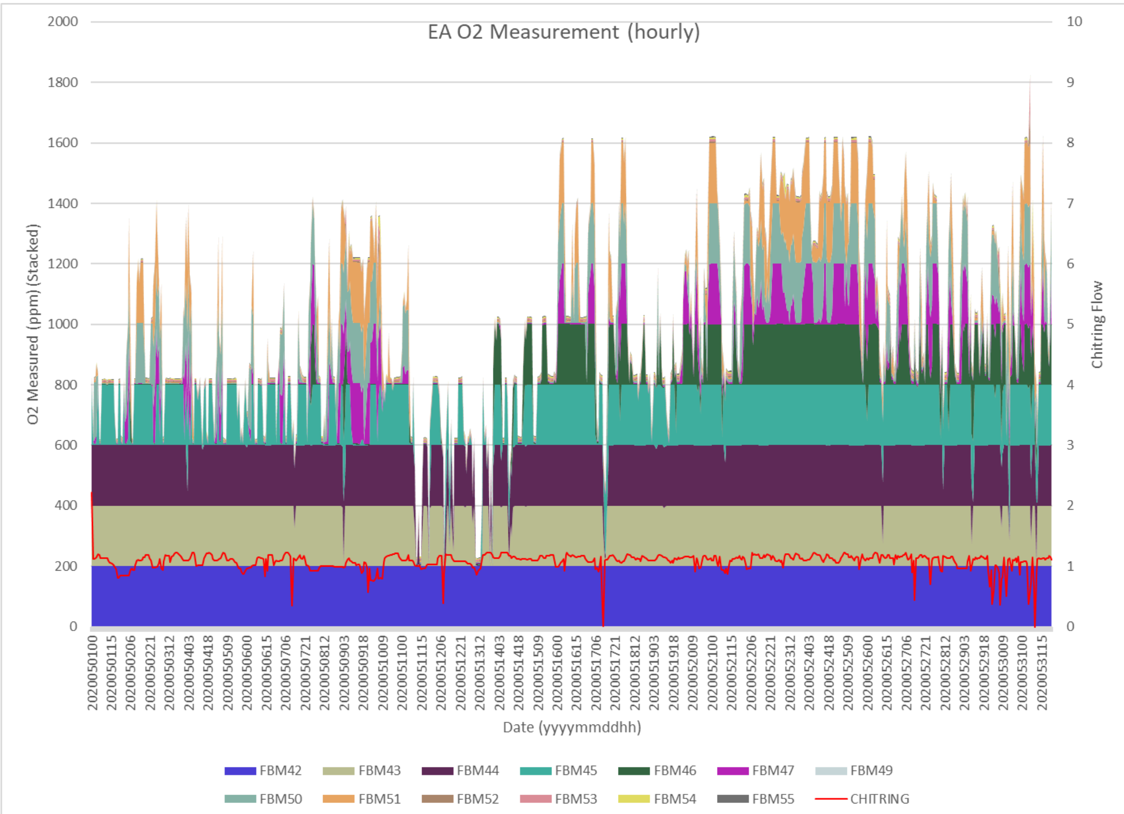

Figure 76 – May 2020

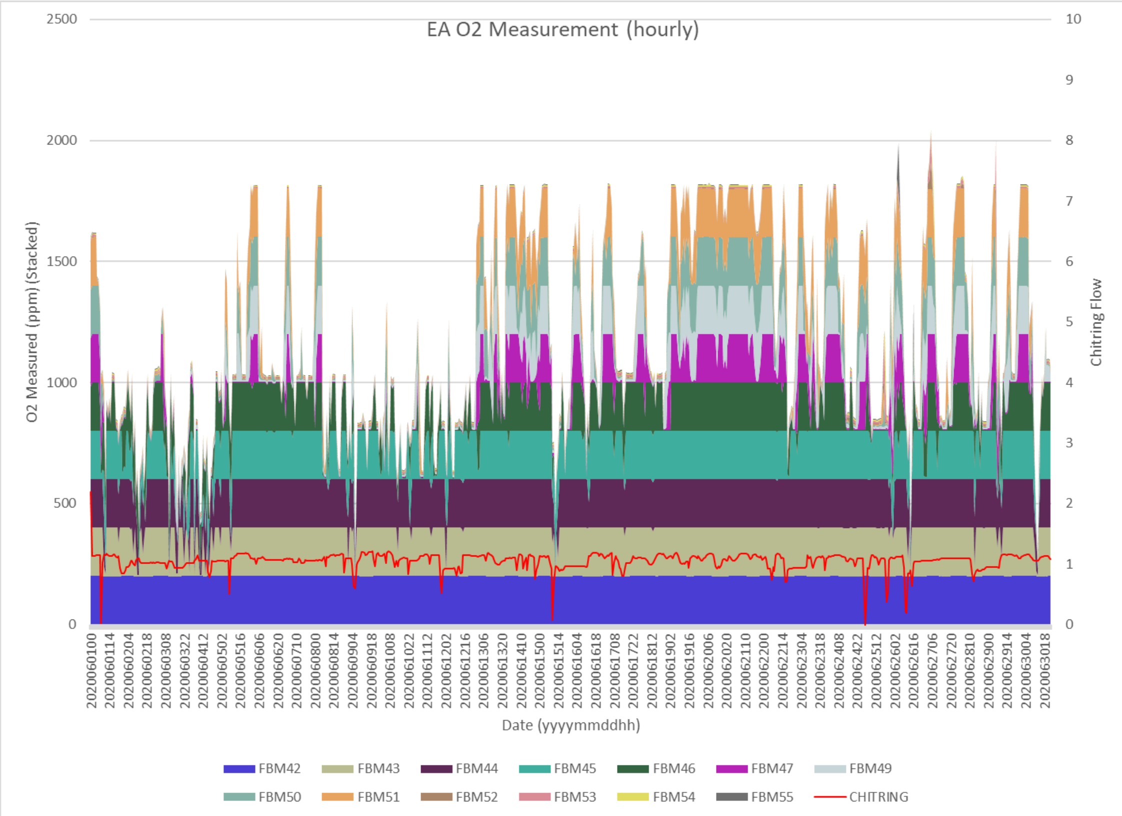

Figure 77 – June 2020

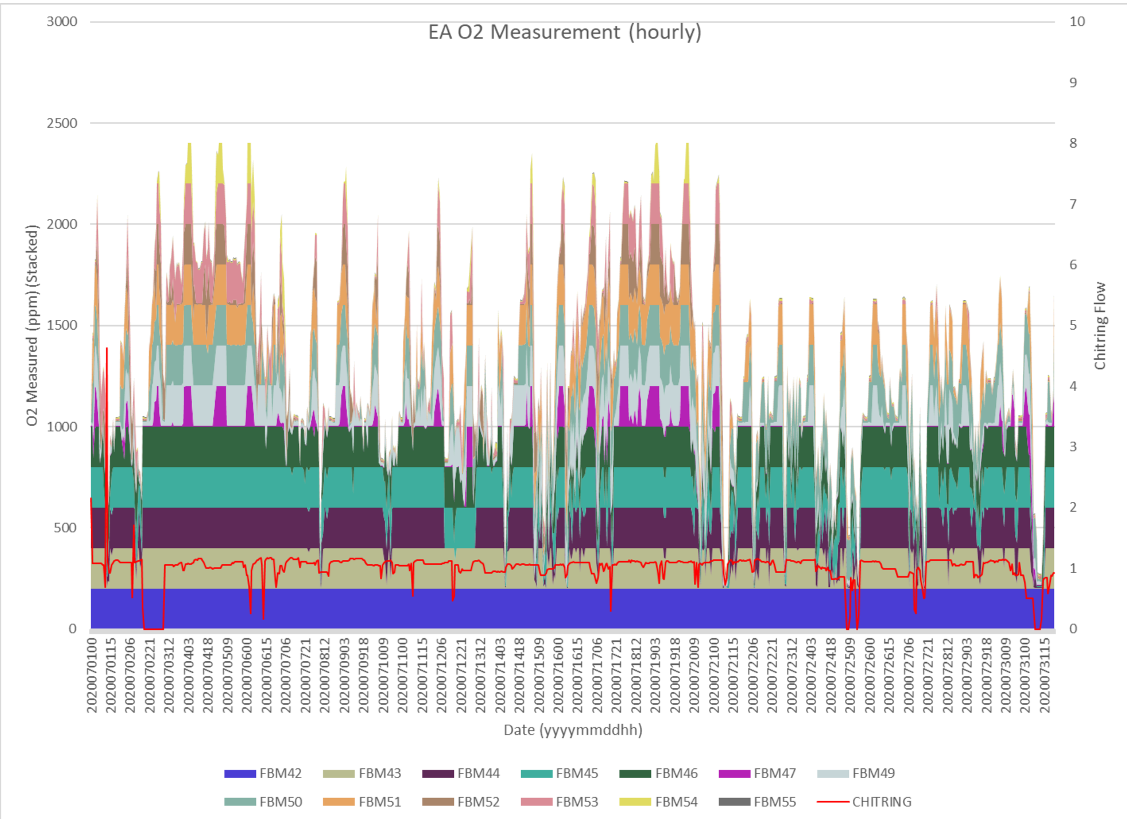

Figure 78 – July 2020

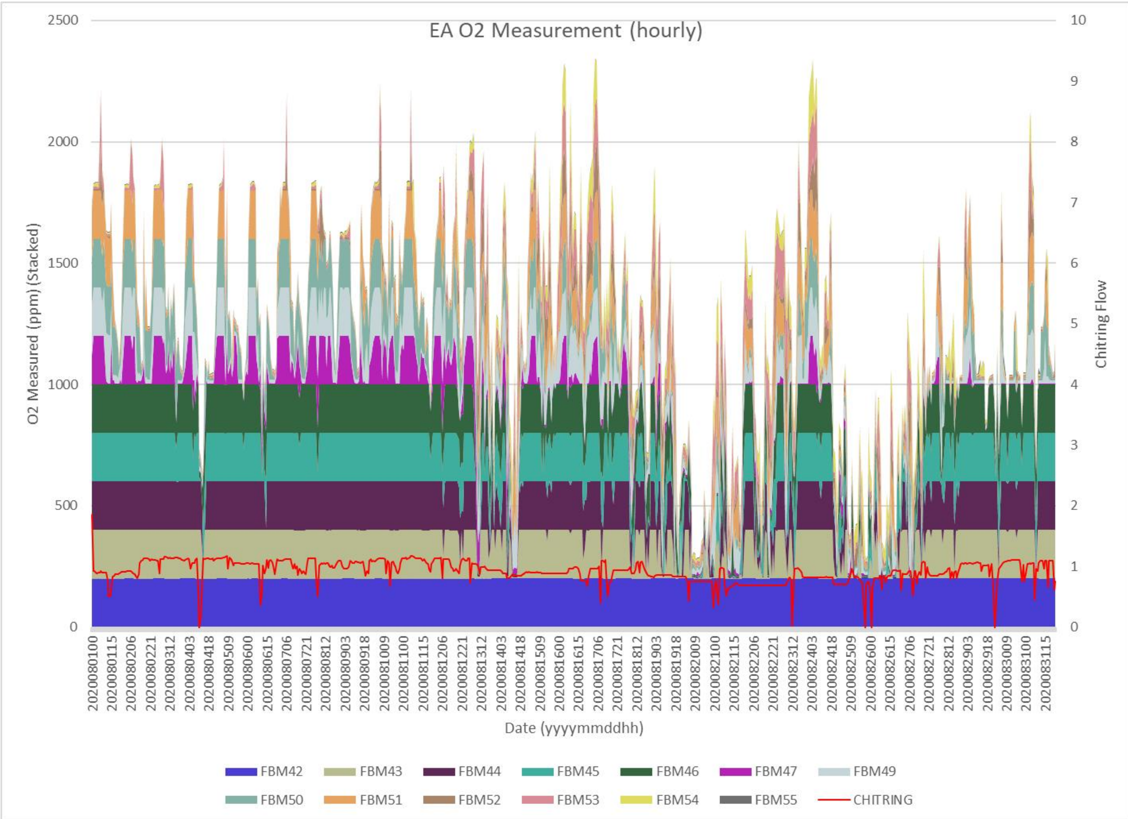

Figure 79 – August 2020

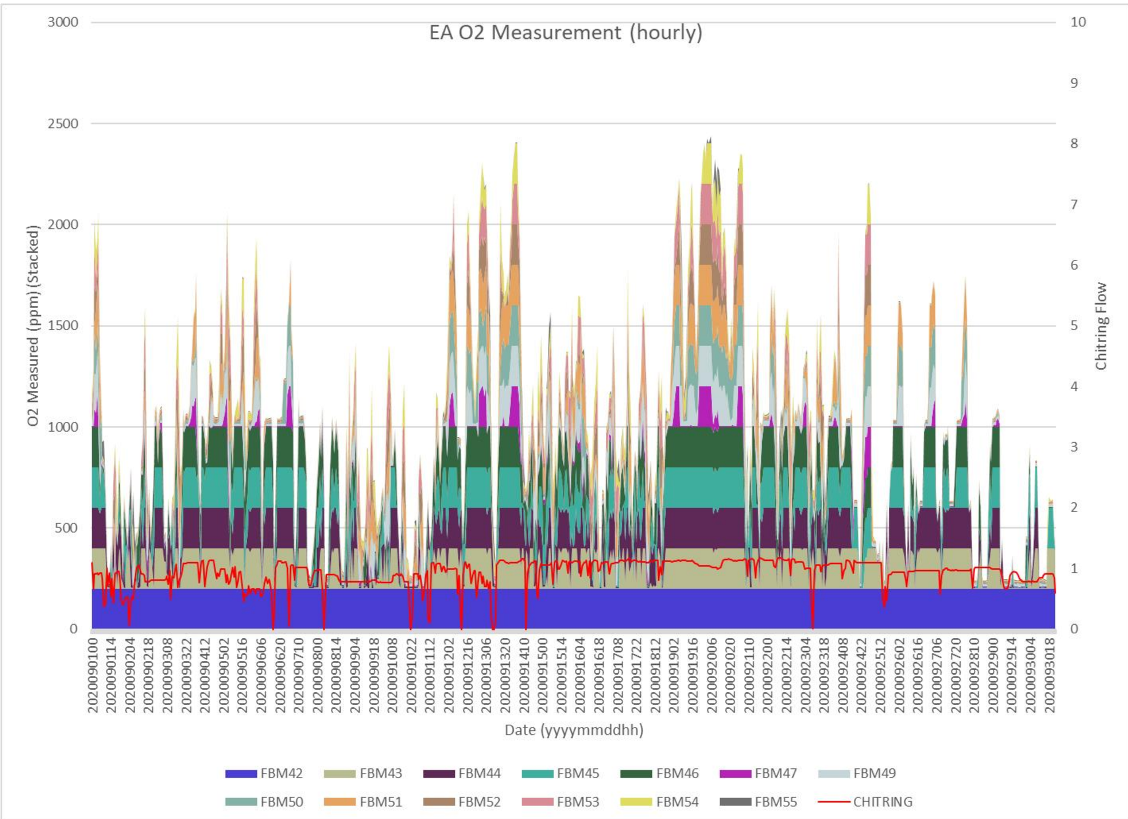

Figure 80 – September 2020

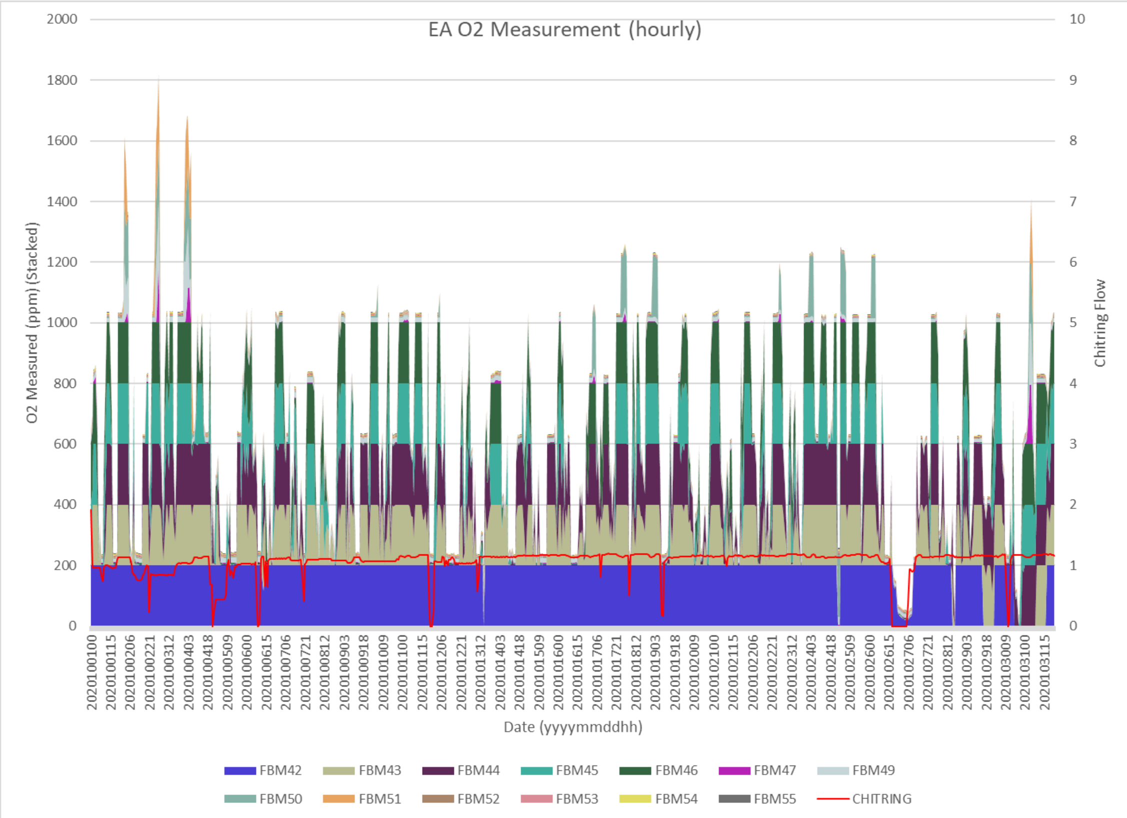

Figure 81 – October 2020

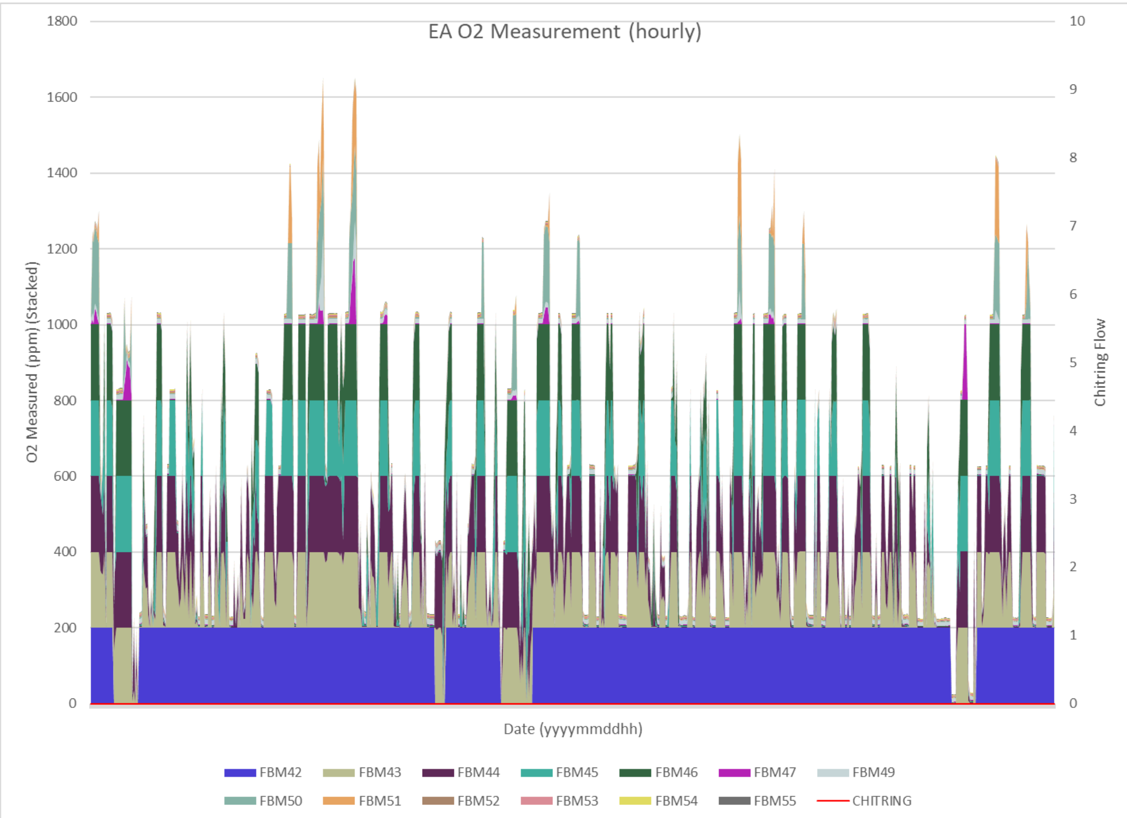

Figure 82 – November 2020

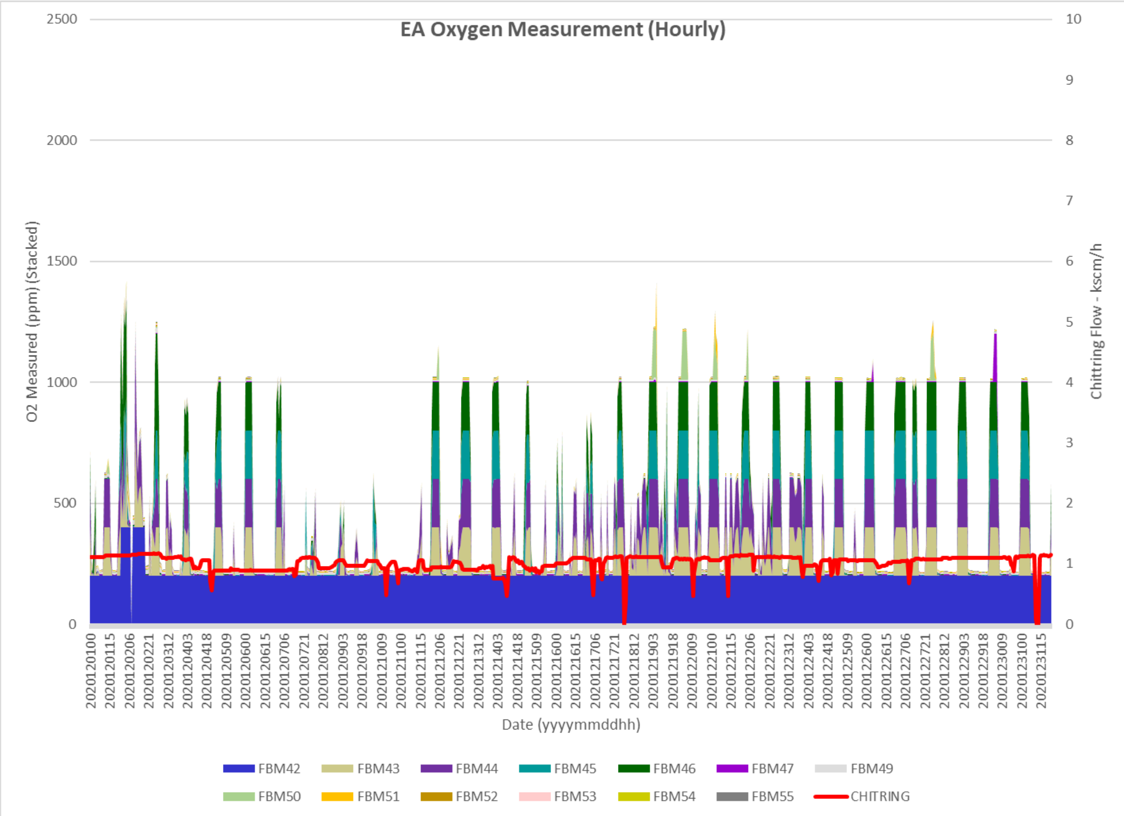

Figure 83 – December 2020

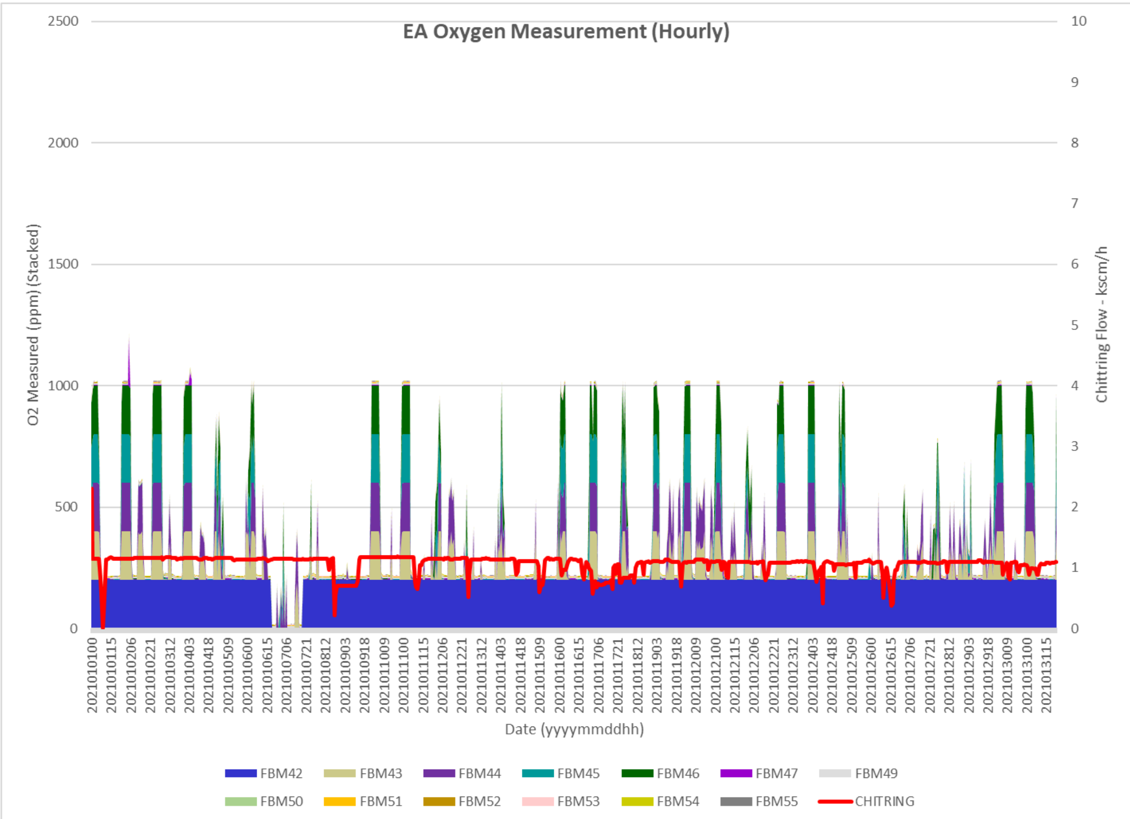

Figure 84 – January 2021

E.3 Oxygen Recordings Cambridge Regulators

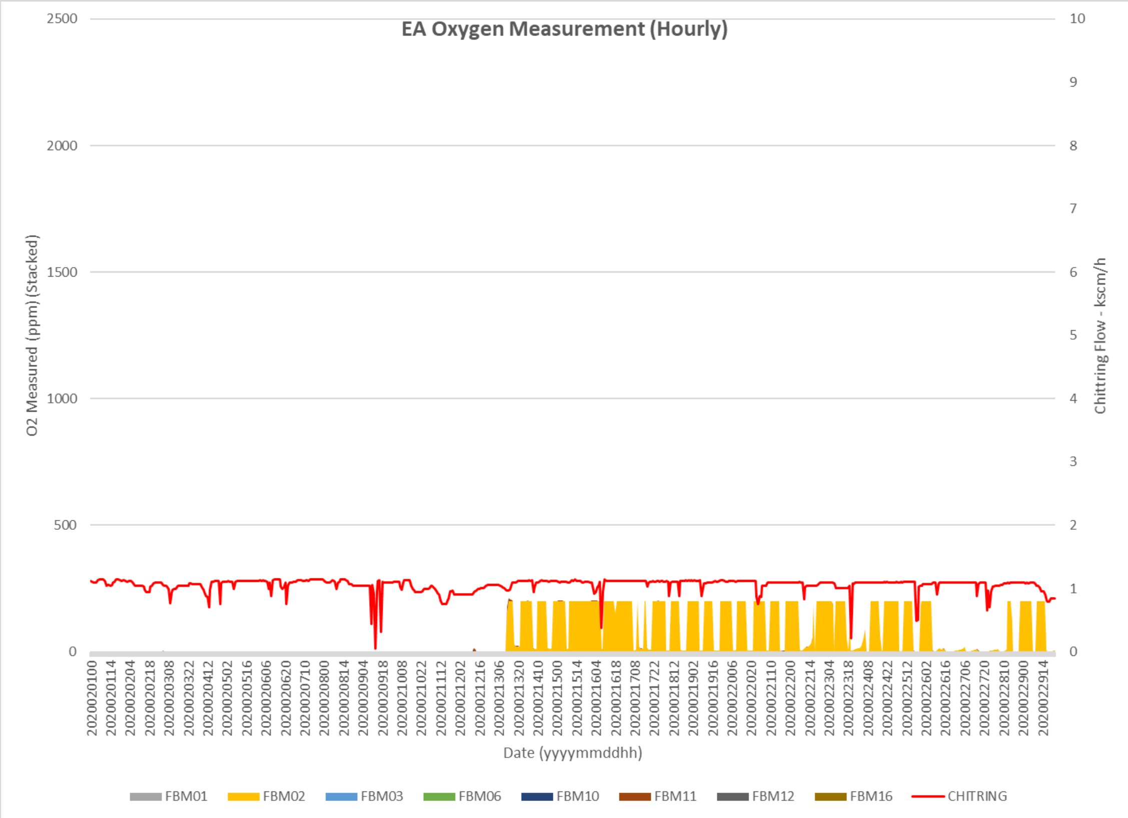

Figure 85 – February 2020

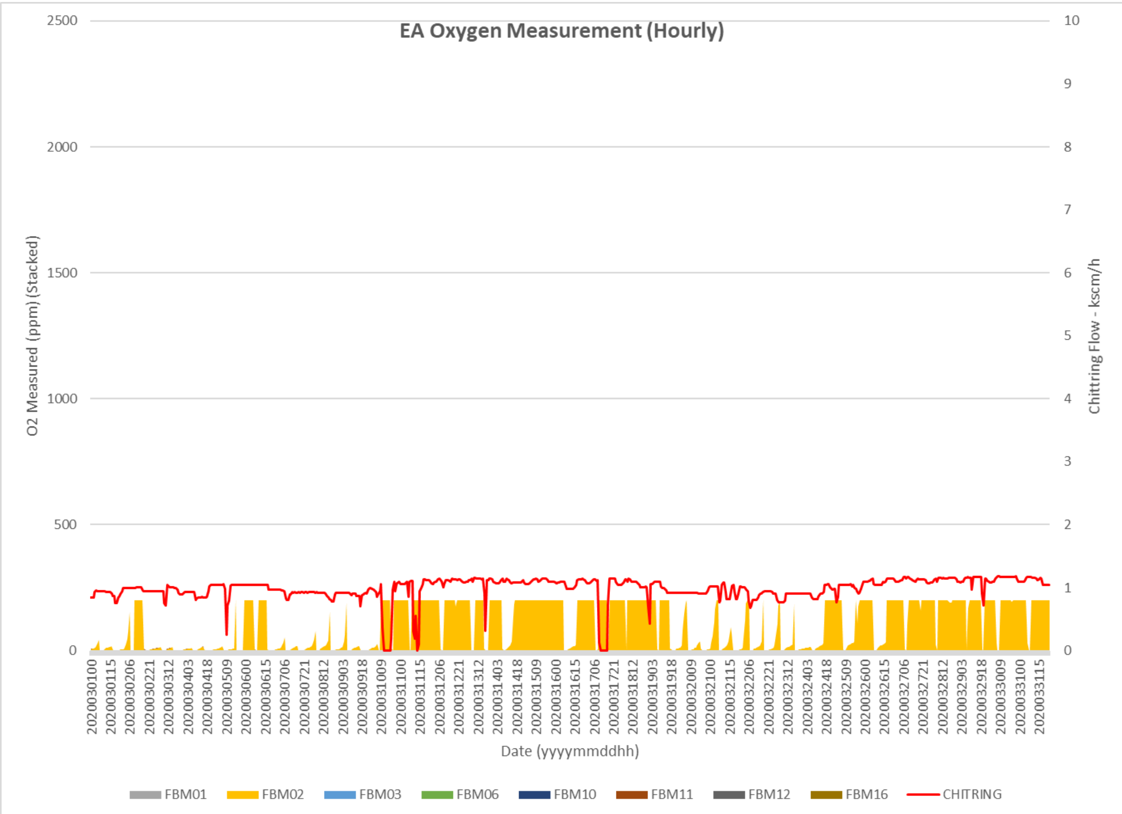

Figure 86 – March 2020

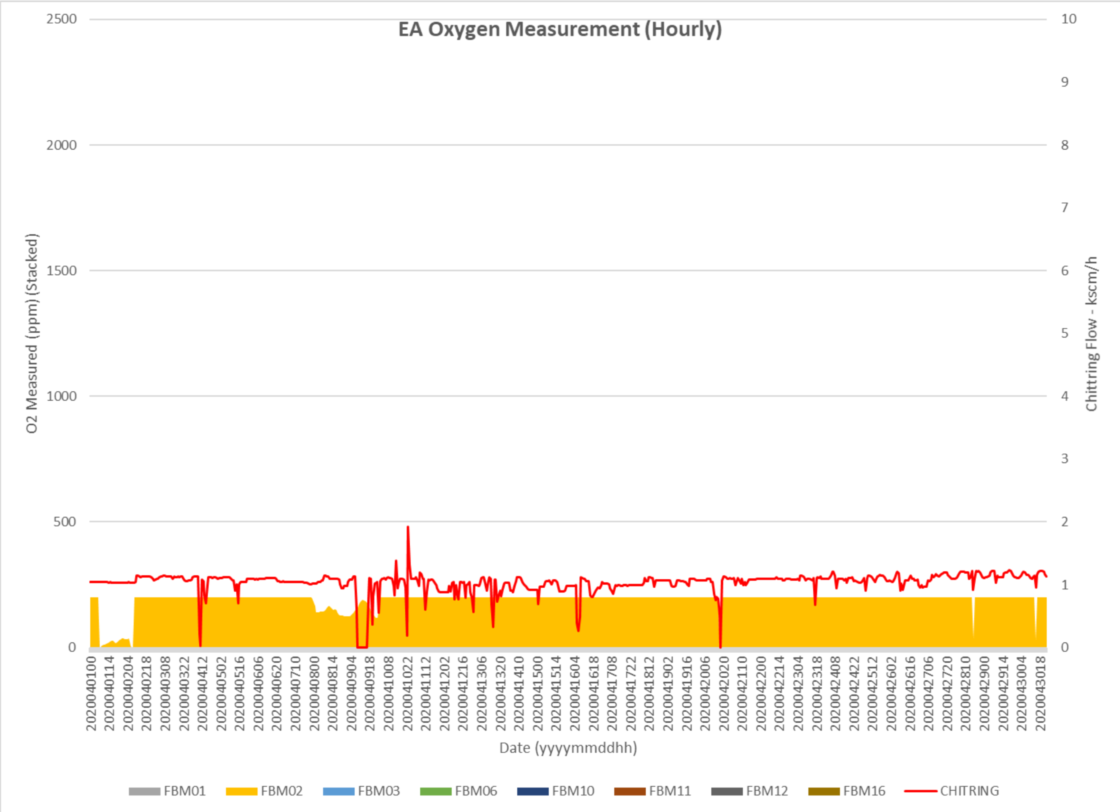

Figure 87 – April 2020

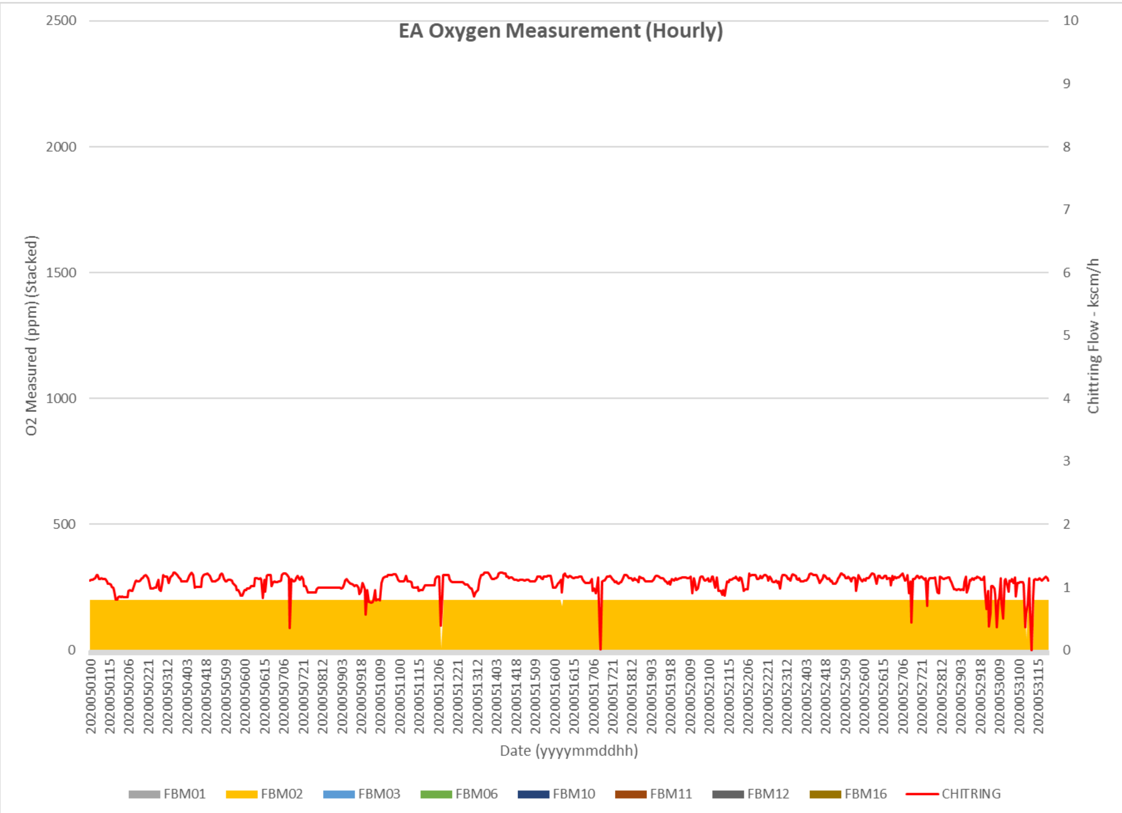

Figure 88 – May 2020

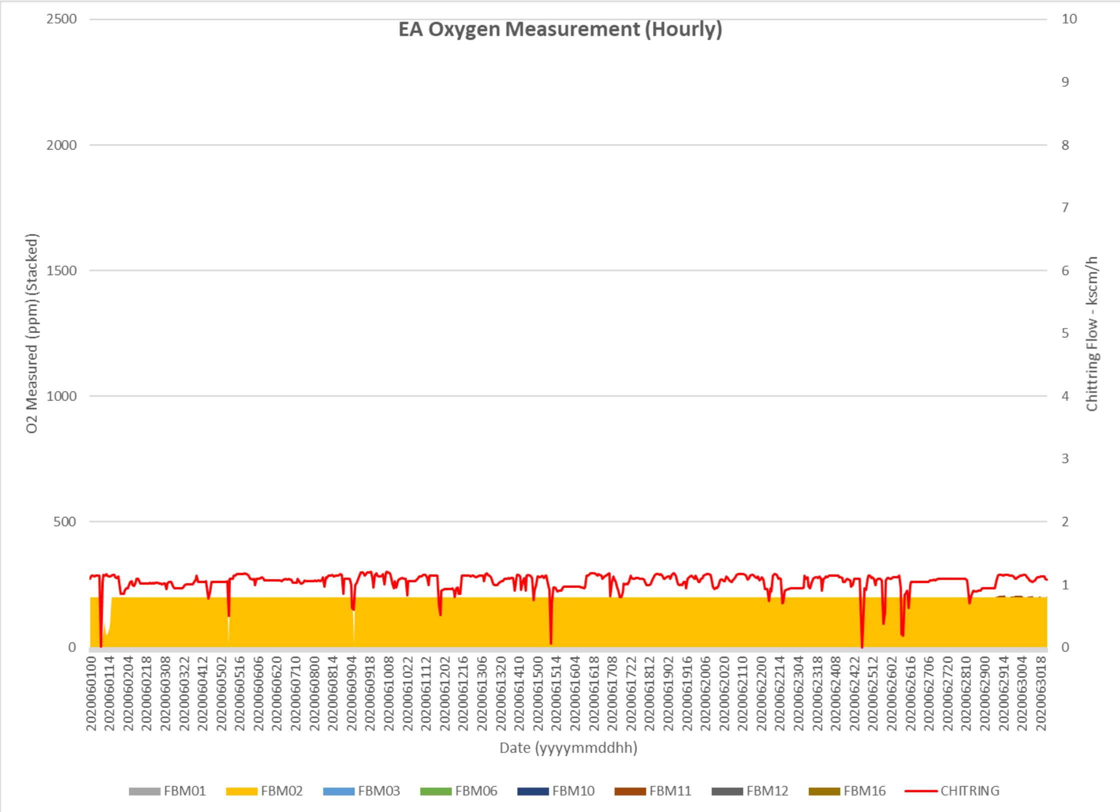

Figure 89 – June 2020

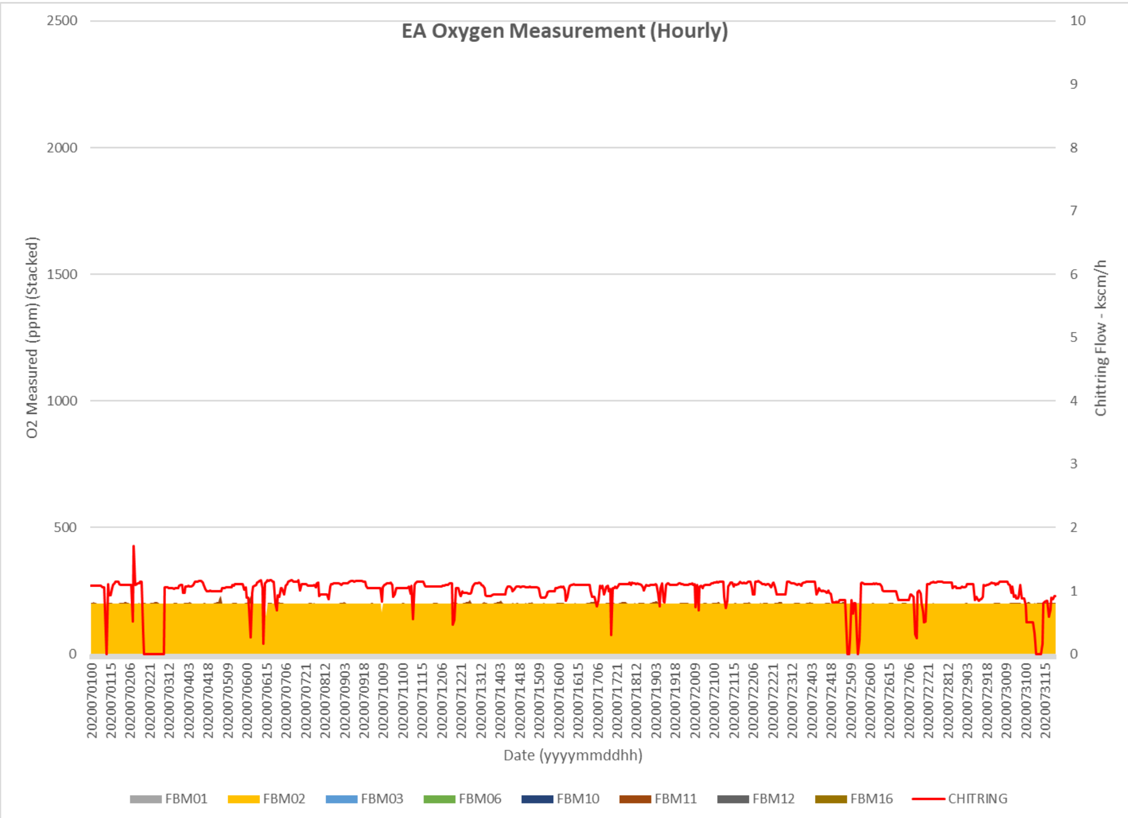

Figure 90 – July 2020

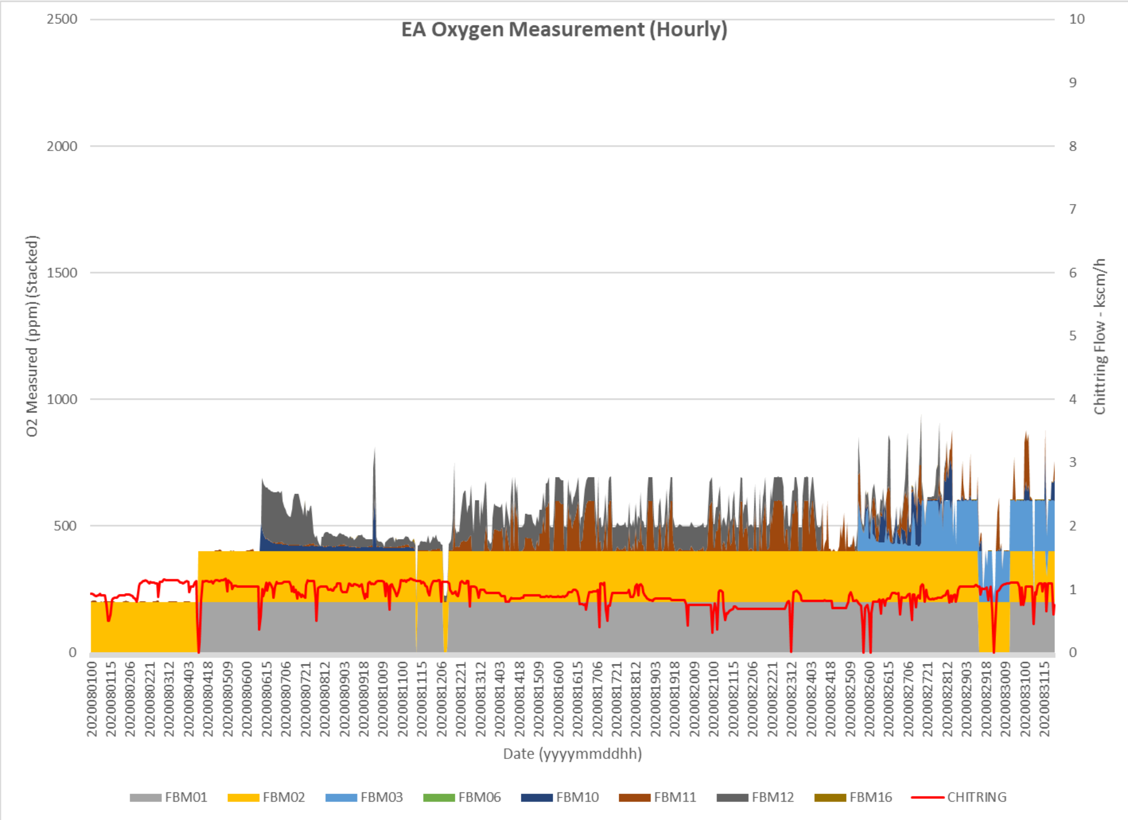

Figure 91 – August 2020

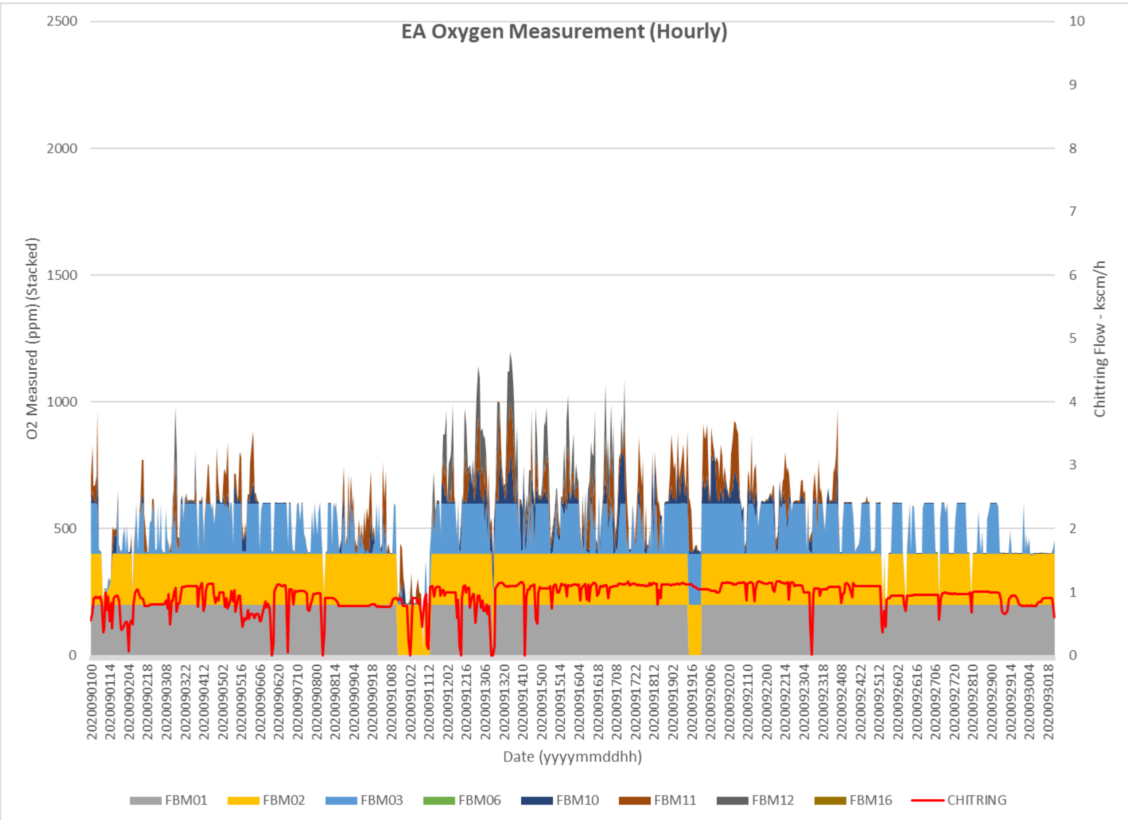

Figure 92 – September 2020

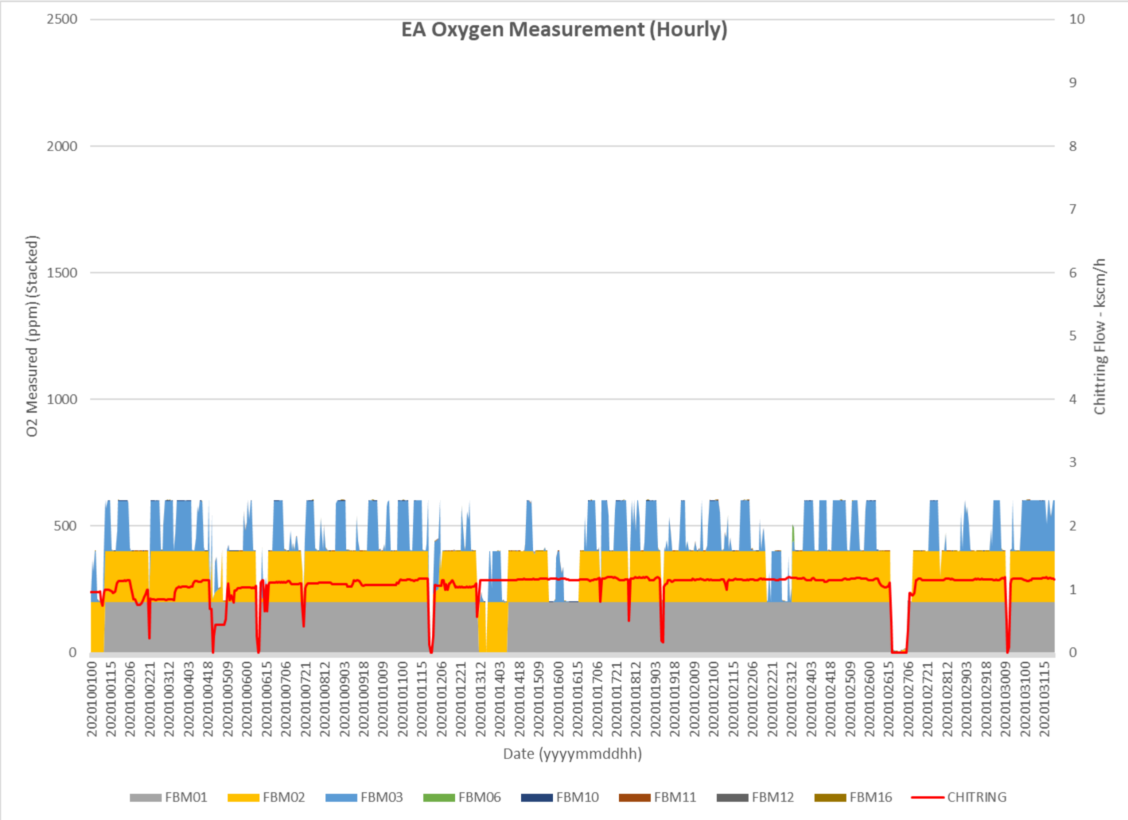

Figure 93 – October 2020

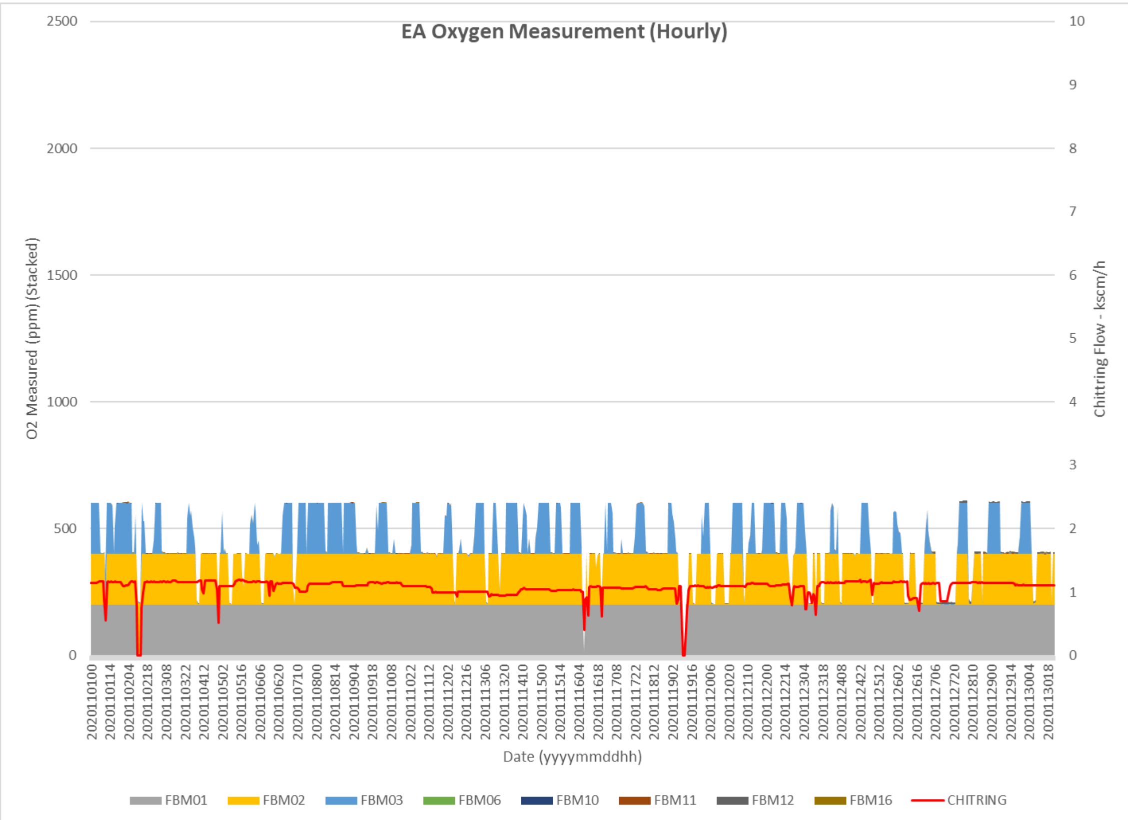

Figure 94 – November 2020

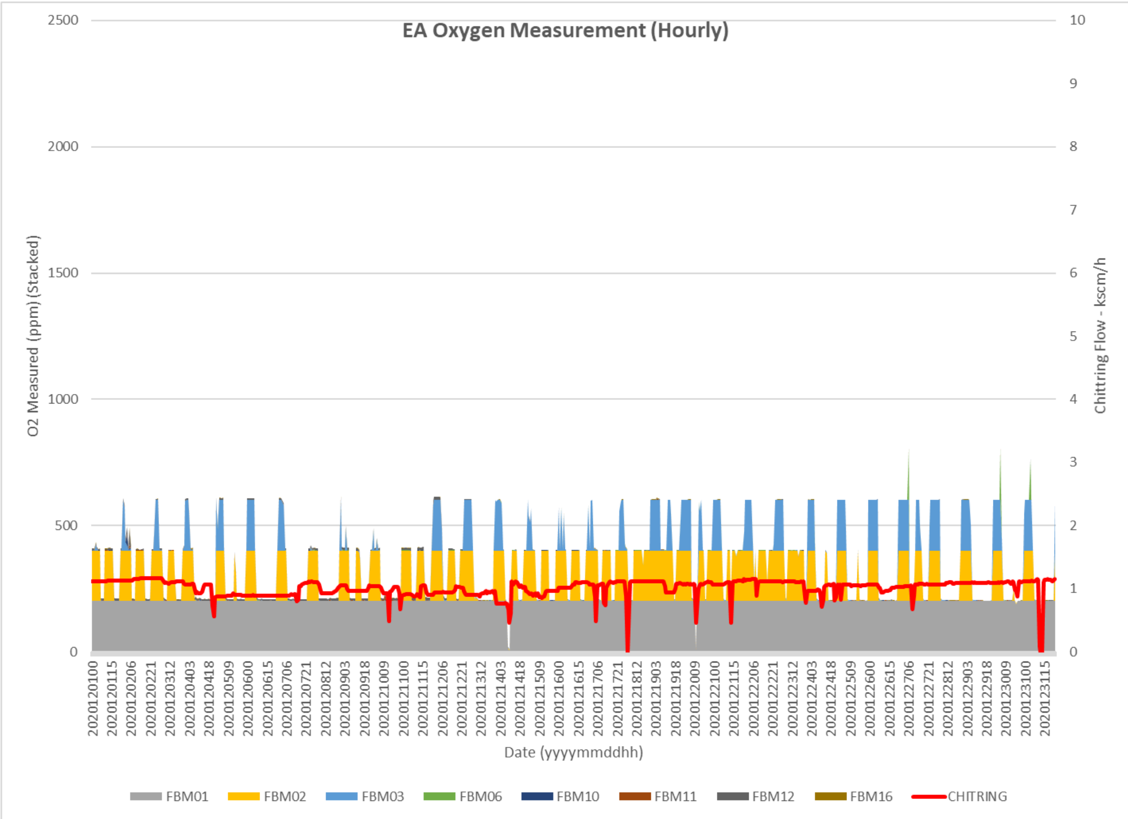

Figure 95 – December 2020

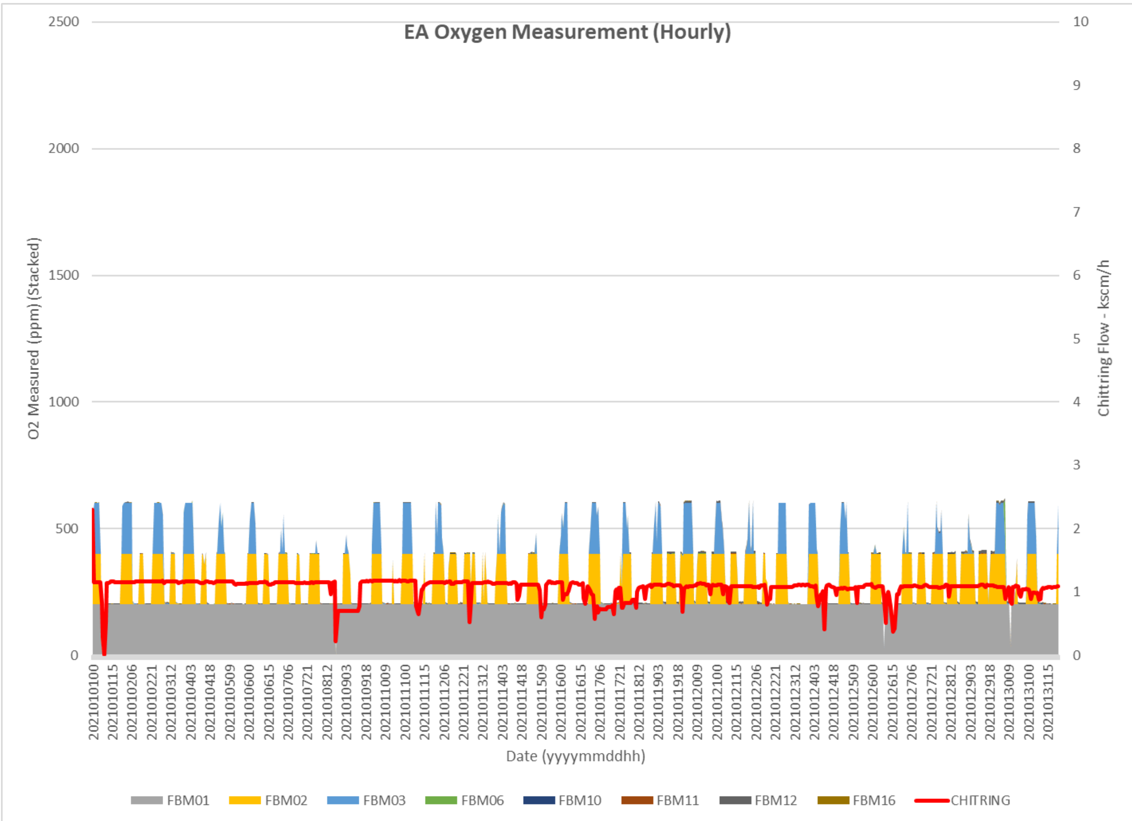

Figure 96 – January 2021

E.4 Oxygen Recordings Lincolnshire Regulators

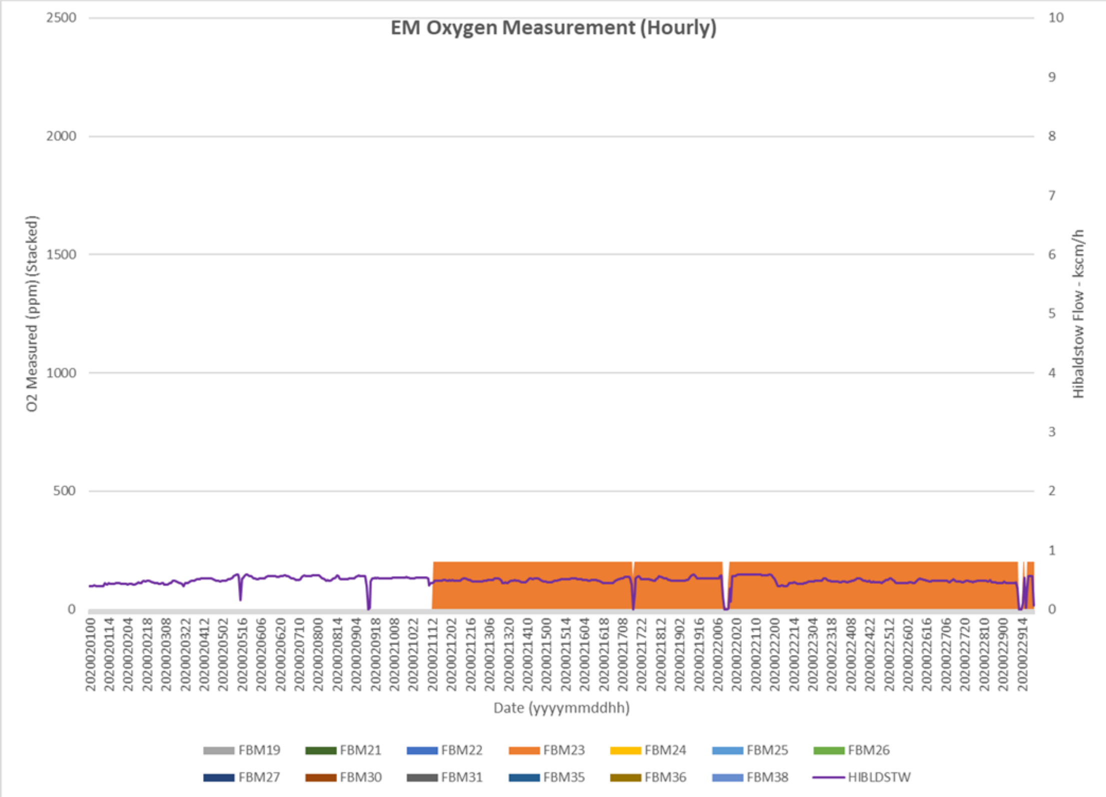

Figure 97 – February 2020

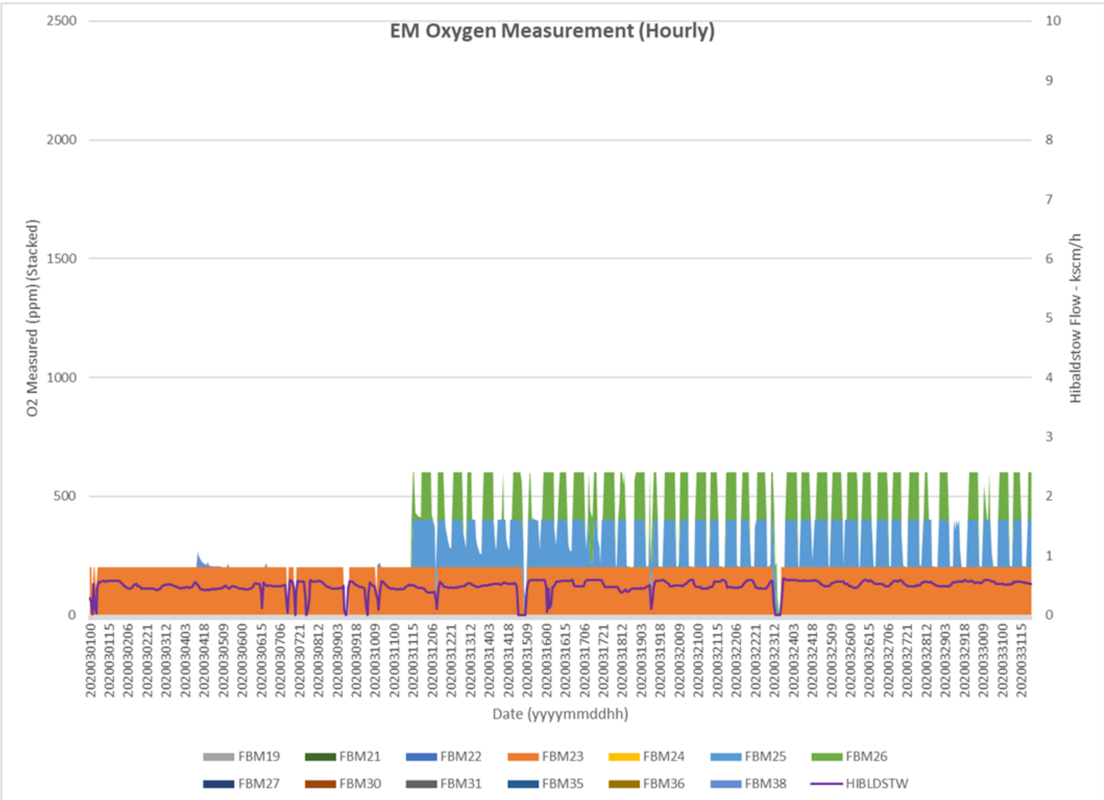

Figure 98 – March 2020

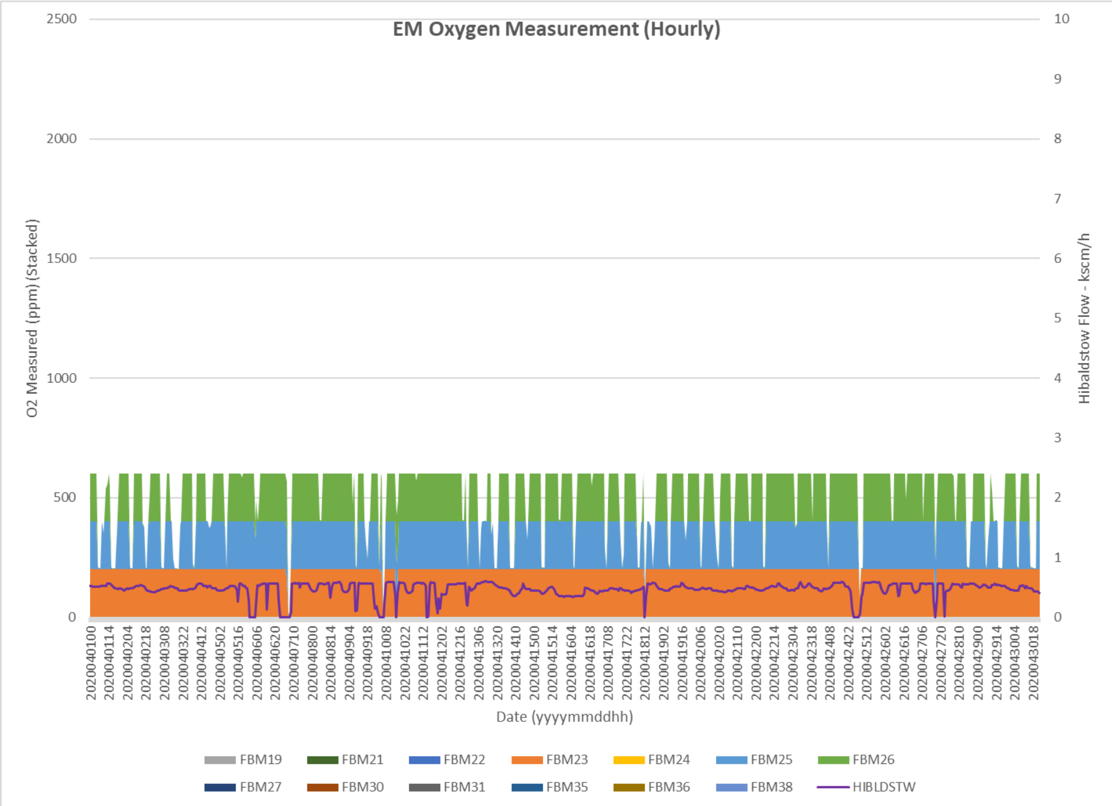

Figure 99 – April 2020

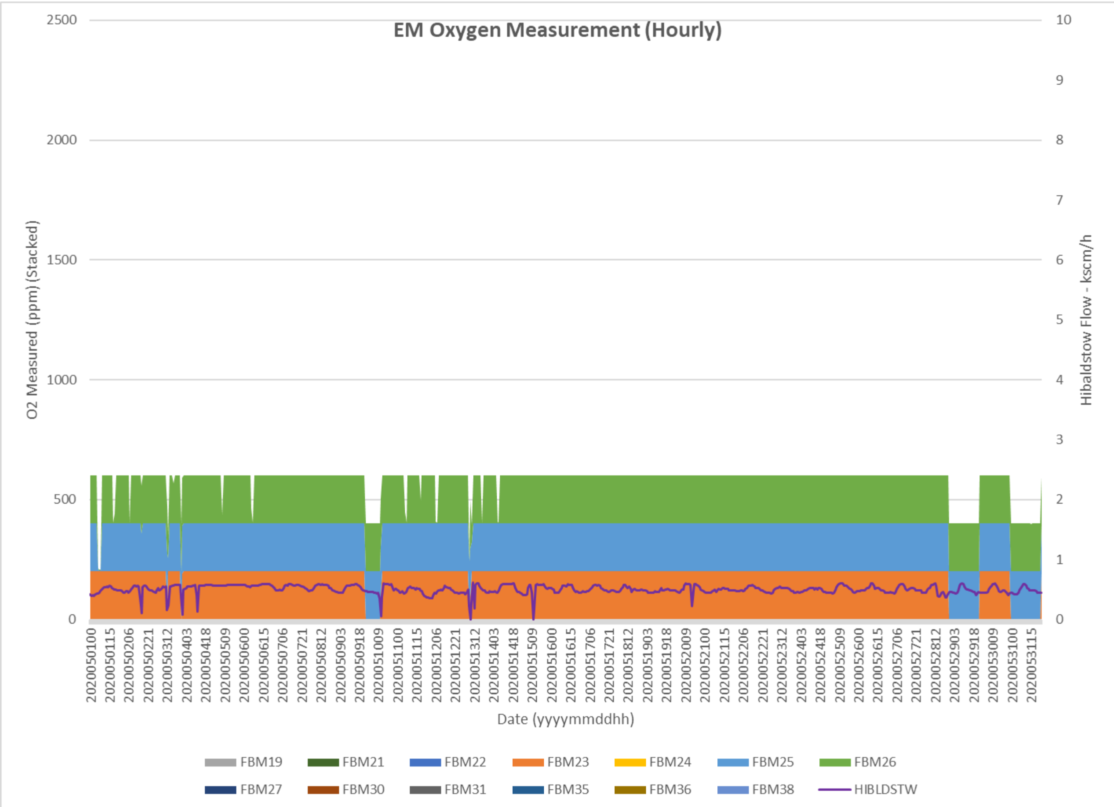

Figure 100 – May 2020

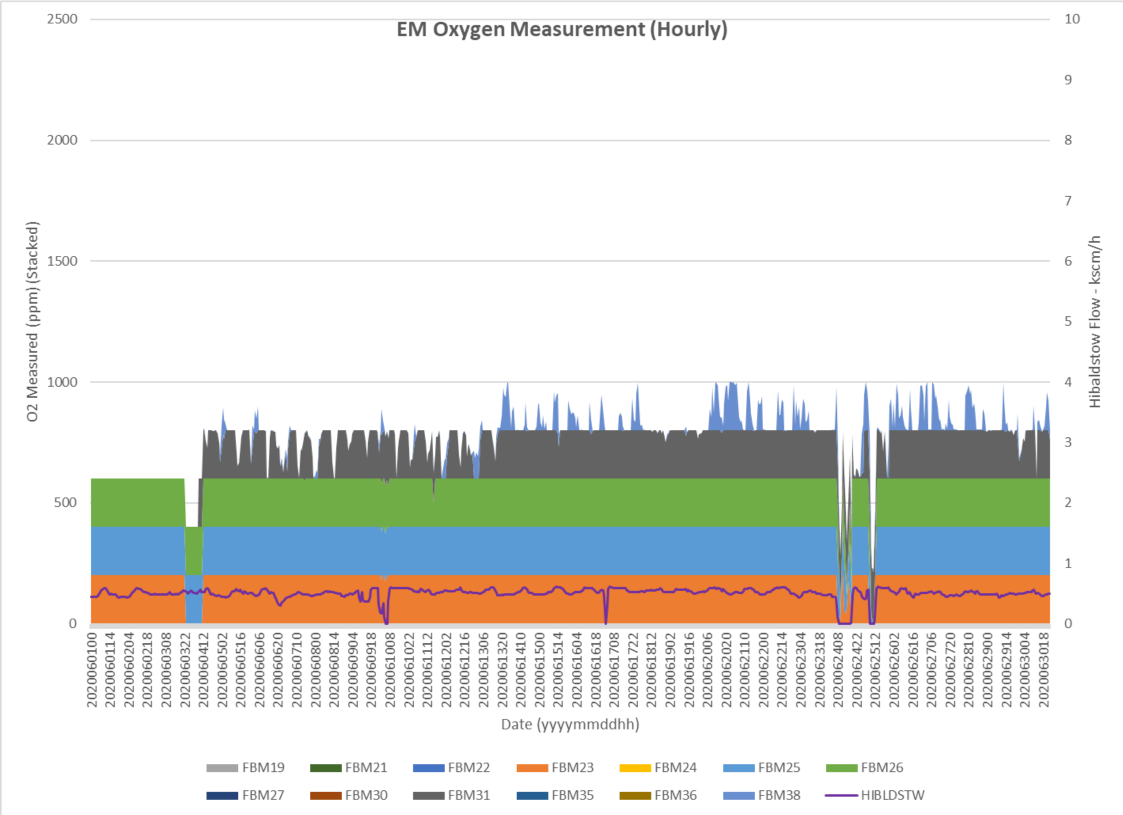

Figure 101 – June 2020

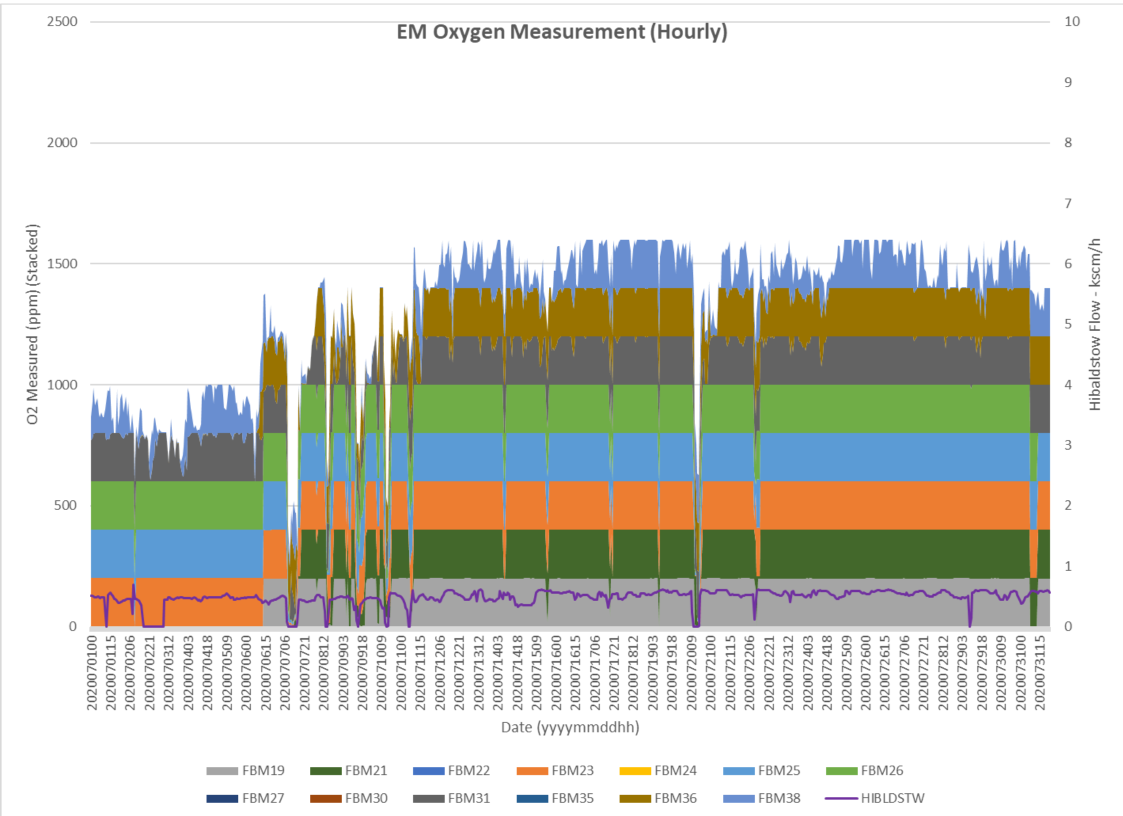

Figure 102 – July 2020

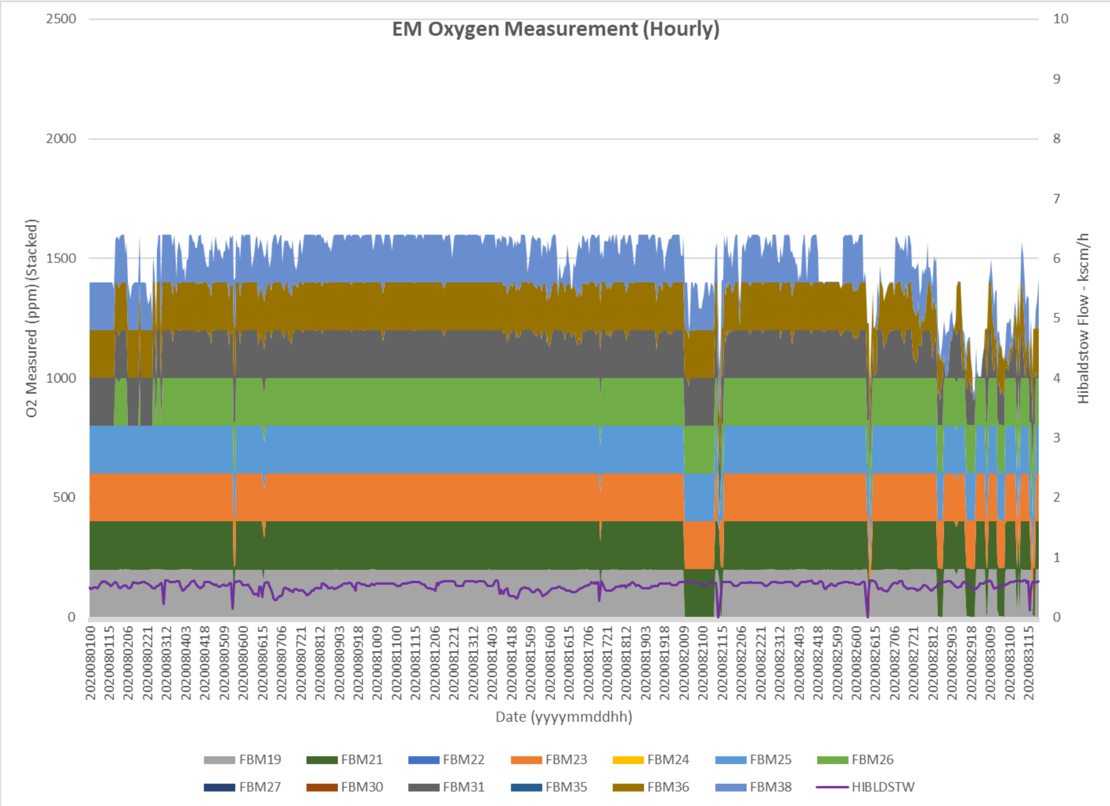

Figure 103 – August 2020

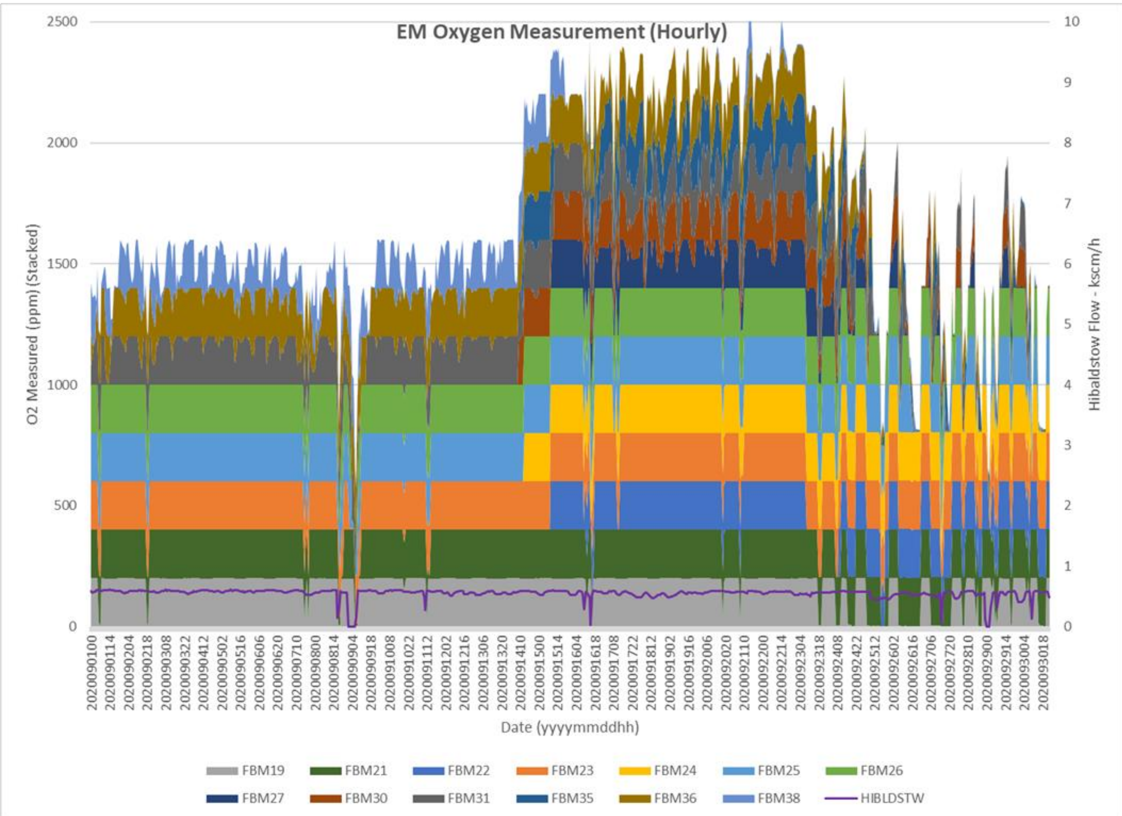

Figure 104 – September 2020

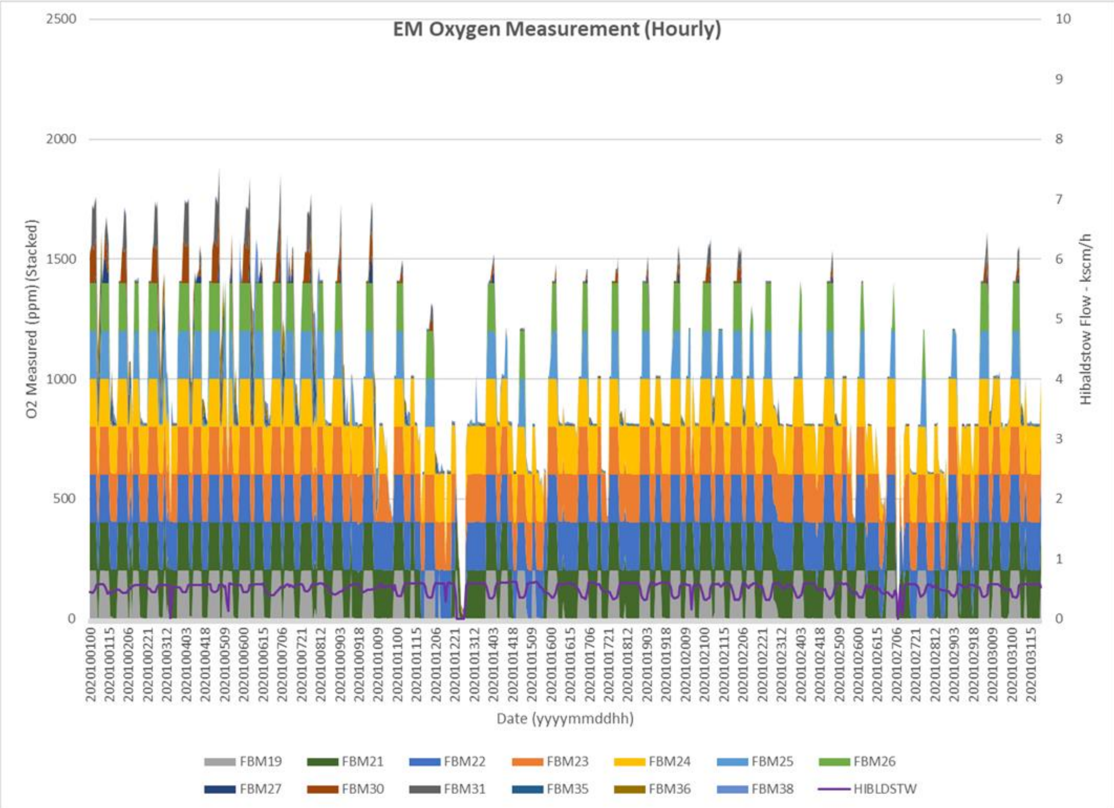

Figure 105 – October 2020

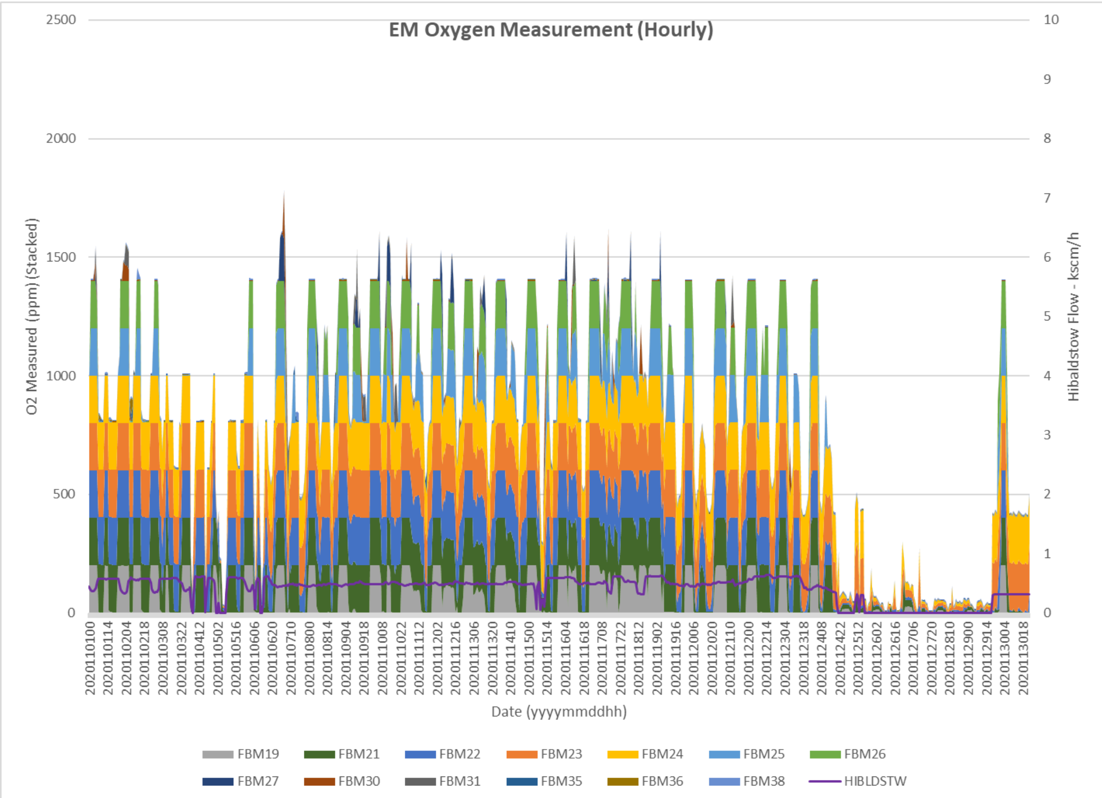

Figure 106 – November 2020

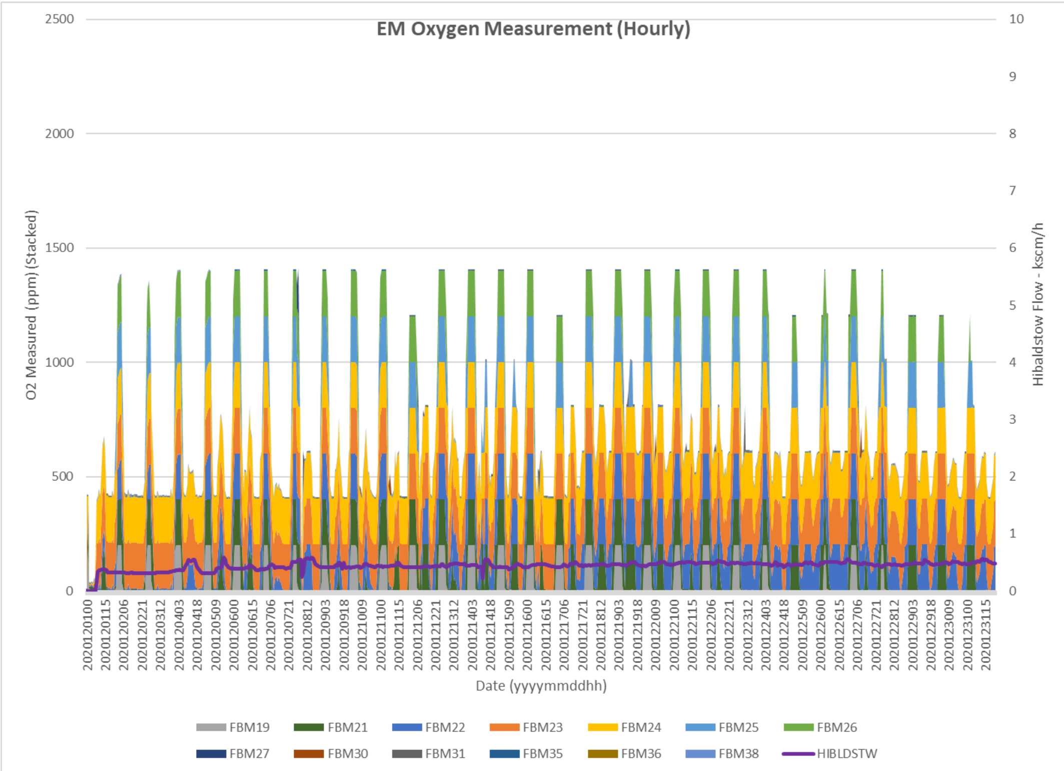

Figure 107 – December 2020

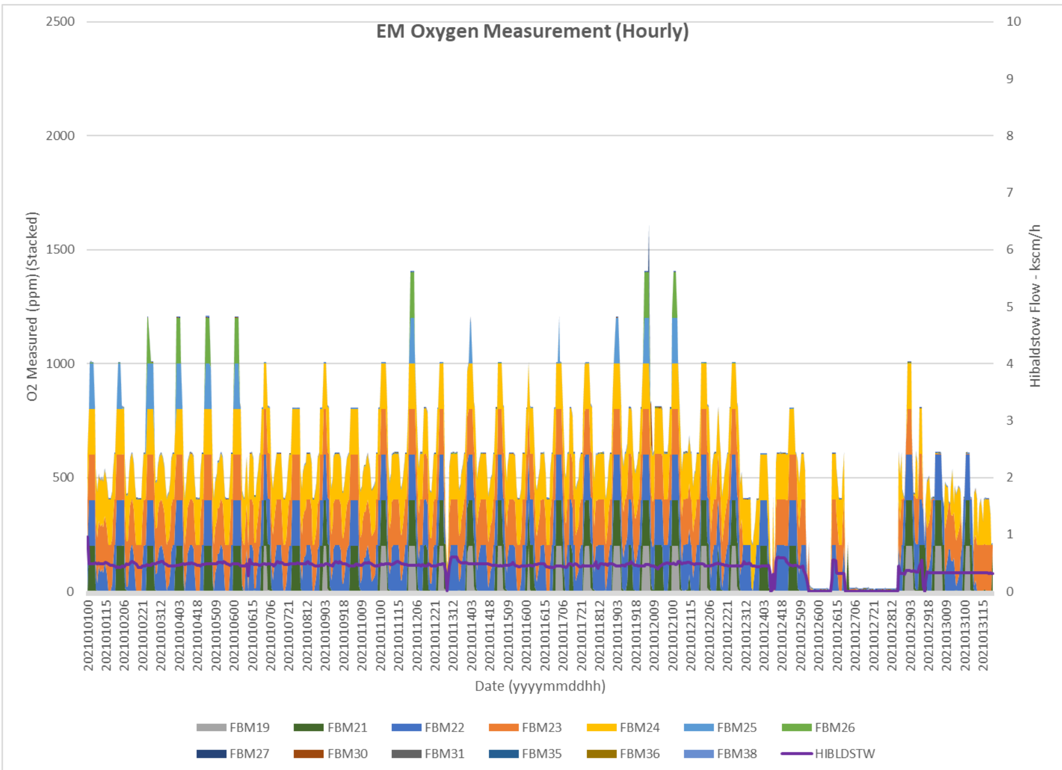

Figure 108 – January 2021

DNV

About DNV

DNV is the independent expert in risk management and assurance, operating in more than 100 countries. Through its broad experience and deep expertise DNV advances safety and sustainable performance, sets industry benchmarks, and inspires and invents solutions.

Whether assessing a new ship design, optimizing the performance of a wind farm, analyzing sensor data from a gas pipeline or certifying a food company's supply chain, DNV enables its customers and their stakeholders to make critical decisions with confidence.

Driven by its purpose, to safeguard life, property, and the environment, DNV helps tackle the challenges and global transformations facing its customers and the world today and is a trusted voice for many of the world's most successful and forward-thinking companies.