

Evidence

Material comparators for end-of-waste decisions

Fuels: natural gas

Report: SC130040/R15 (ShARE 25)

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SC130040/R15 (ShARE 25)

Executive summary

This report details the work undertaken to characterise natural gas, a key comparator. This information will inform end-of-waste assessments for waste-derived materials intended to replace natural gas as a fuel.

The Waste Framework Directive (Article 6) provides criteria for identifying when a waste material has become a product and no longer needs to be regulated as a waste. Through Article 6 and national case law** the environmental and human health impacts from materials in comparison with their non-waste material alternatives must be considered.

** 'It should be enough that the holder has converted the waste material into a distinct, marketable product, which can be used in exactly the same way as a [non-waste material], and with no worse environmental effects.'

Syngas from pyrolysis and gasification plants no longer needs to be regulated as a waste if the product reaches end of waste. In addition when such syngas is used as a fuel, the Industrial Emissions Directive requires that it must not produce emissions higher than those associated with burning natural gas.

Market research was used to define natural gas as an ordinary comparator and a literature review was used to identify any existing published data.

Nine samples of natural gas were collected from one gas shipper in England. Analytical data from these samples are presented in this report, together with existing published data.

We recommend comparing the concentrations of analytes in the comparators dataset to the concentrations in the waste-derived material, paying attention to the higher values. This comparison does not constitute a pass/fail test or an end of waste view. It will provide an indication of whether the waste material contains similar levels of analytes to non-waste materials and whether an end-of-waste application may be appropriate or that further analysis or improved treatment processes may be warranted.

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1 Introduction

To define end-of-waste criteria, the Environment Agency requires a set of ordinary material comparator data for use as a benchmark against which other materials and wastes can be assessed.

The Waste Framework Directive (Article 6) provides criteria for identifying when a waste material has become a product and no longer needs to be regulated as a waste. Through Article 6, the case law requires anyone making a determination to consider the environmental and human health impacts from materials in comparison with their non-waste material alternatives.

‘It should be enough that the holder has converted the waste material into a distinct, marketable product, which can be used in exactly the same way as a [non-waste material], and with no worse environmental effects.’

Syngas from pyrolysis and gasification plants no longer needs to be regulated as a waste if the product reaches end of waste. In addition when such syngas is used as a fuel, the Industrial Emissions Directive requires that it must not produce emissions higher than those associated with burning natural gas.

The purpose of this report is to provide an evidence base of the composition and characteristics of natural gas which is defined as an ordinary material comparator that is currently permitted for use as a fuel.

This report provides the results from the primary sampling and analysis of nine natural gas samples.

2 Definition

2.1 Natural gas definition

2.1.1 Origin

Natural gas is a hydrocarbon, a fossil fuel that occurs in nature as economic accumulations trapped in structures and reservoir rocks beneath the Earth's surface (BGS, 2011). Natural gas was formed when the prehistoric remains of animals and plants were buried and subjected to high temperatures and pressures for millions of years. Natural gas comprises mostly methane (EDF, 2015); thus is valued as a source of energy (BGS, 2011). Natural gas is non-renewable resource (BGS, 2011).

2.1.2 Uses

The UK is highly dependent on gas as primary source of energy (BGS, 2011). UK gas consumption can be split into four broad sectors:

- Electricity generation;
- Industry;
- Domestic; and
- Other (e.g. government, commercial and agriculture) (Dodds and McDowell, 2013).

2.1.3 Material properties relevant to use

Natural gas is a combustible gas that is a mixture of simple hydrocarbon compounds. It contains primarily methane, along with small amounts of ethane, butane, pentane, and propane. Natural gas does not contain carbon monoxide. The by-products of burning natural gas are primarily carbon dioxide and water vapour. Natural gas is colourless, tasteless and odourless. Because it is odourless, an odorant (80% tertiarybutyl mercaptan, 20% dimethyl sulphide) is added to the gas, to give the gas a distinctive smell. Other beneficial properties of natural gas are a high ignition temperature and a narrow flammability range, meaning natural gas will ignite at temperatures above 593°degrees and burn at a mix of 4 – 15% volume in air (St. Lawrence Gas, 2015).

2.1.4 National Grid specification

The National Grid specification set out below is acceptable for most locations and encompasses but is not limited to the statutory requirements set out in the Gas Safety (Management) Regulations 1996 (GS(M)R).

Table 1: National Grid specification (National Grid, 2012)

Parameter	Limit
Hydrogen Sulphide	Not more than 5mg/m ³
Total Sulphur	Not more than 50 mg/m ³
Hydrogen	Not more than 0.1% (molar)
Oxygen	Not more than 0.001% (molar)
Hydrocarbon Dewpoint	Not more than -2°C at any pressure up to 85bar
Water Dewpoint	Not more than -10°C at 85bar
Wobbe Index (real gross dry)	The Wobbe Number shall be in the range 47.20 to 51.41MJ/m ³
Incomplete Combustion Factor (ICF)	Not more than 0.48
Soot Index (SI)	Not more than 0.60
Gross Calorific Value (real gross dry)	The Gross Calorific Value (real gross dry) shall be in the range 36.9 to 42.3MJ/m ³ , in compliance with the Wobbe Number, ICF and SI limits described above
Inerts	Not more than 7.0% (molar) subject to Carbon Dioxide not more than 2.0% (molar)
Contaminants	The gas shall not contain solid, liquid or gaseous material that may interfere with the integrity or operation of pipes or any gas appliance within the meaning of regulation 2(1) of the Gas Safety (Installation and Use) Regulations 1998 that a consumer could reasonably be expected to operate
Organo Halides	Not more than 1.5 mg/m ³
Radioactivity	Not more than 5 Becquerels/g
Odourant	Gas shall be odourised with odourant NB (80% tertiarybutyl mercaptan, 20% dimethyl sulphide) at an odourant injection rate of 6 mg/m ³ , which may be varied at the Operator's request by up to plus or minus 2 mg/m ³ to meet operational circumstances
Pressure	The delivery pressure shall be the pressure required to deliver natural gas at the Delivery Point into the Entry Facility at any time taking into account the back pressure of our System at the Delivery Point as the same shall vary from time to time. The entry pressure shall not exceed the Maximum Operating Pressure at the Delivery Point
Delivery Temperature	Between 1°C and 38°C

2.2 Natural gas sub types

The natural gas used in the UK can be divided into sub types based on natural gas sources, both native and imported. UK gas originates from one of the following four routes:

- UK continental shelf gas
- UK onshore gas
- Interconnector pipeline imports. There are currently three gas interconnectors which connect to the National Transmission System, as well as a pipeline for import of Norwegian gas. The pipelines are:
 - IUK interconnector to Belgium
 - Balgzand to Bacton Line (BBL) to the Netherlands
 - Moffat to the Republic of Ireland interconnector
 - Langeled pipeline to Norway
- Liquefied natural gas imports (predominantly from Qatar)

2.3 Natural gas sources

The UK imported 45% of the natural gas it used in 2009 and, as North Sea reserves dwindle, this is predicted to rise to 69% by 2019 (in 2014, imports accounted for around half of the gas used). The UK imports natural gas from a variety of countries (DECC, 2014) as shown in Figure 1.

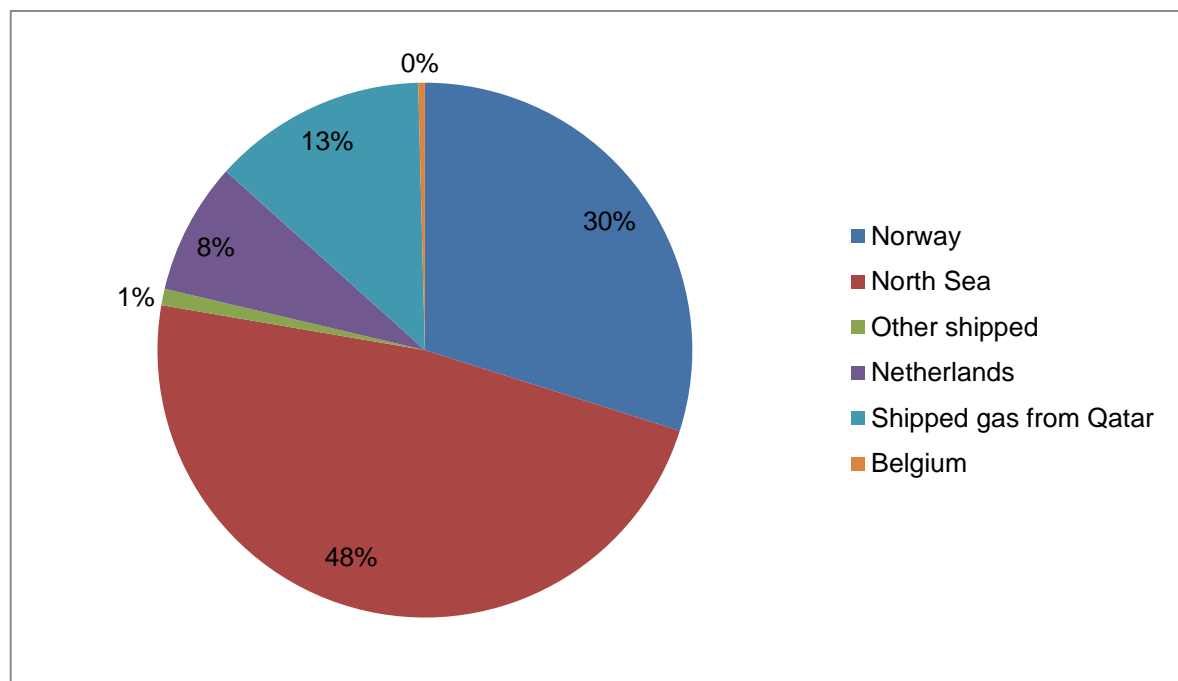


Figure 1 UK natural gas sources (DECC, 2014)

3 Material sources and sampling procedures

A number of gas shippers were contacted during the project. Due to the complex nature of the relationships between gas producers, shippers and distributors, obtaining approval to take samples proved to be difficult. Hence, it was only possible to sample from one gas shipper within the project timescales.

Nine natural gas samples were obtained from one gas shipper in England. Samples were taken during visits on three separate days, from the continuous stream of gas passing through the shipper's facility. On each of the three sampling visits, triplicate samples were taken, with one sample approximately every ten minutes. The natural gas origin is the Southern North Sea.

All sampling was undertaken by Intertek, a specialist natural gas sampling company. Sampling was undertaken in accordance with Intertek's internal procedure CBA 107 written in accordance with the company Quality, Health, Safety and Environment system.

4 Analytical parameters

The main parameters determined, together with units of measurement, are summarised in Table 2. The analytical suite was developed by the steering board made up of members of the relevant environmental regulators from Great Britain and Northern Ireland and The Republic of Ireland.

Testing was carried out in accordance with in-house methods documented by SAL and Intertek. Specific tests used are outlined in the tables. Calorific value (CV) and Wobbe Index data was sourced directly from continuous monitors available on the gas shipper's site. During sampling this data was noted in relation to each sample.

Table 2: Natural gas analytical suite

Parameter	Test method used	Unit	Limit of detection (LOD)
Antimony (Sb)			0.3
Arsenic (As)			0.6
Cadmium (Cd)			0.2
Cobalt (Co)			0.1
Chromium (Cr)			0.2
Copper (Cu)			0.2
Lead (Pb)			0.1
Mercury (Hg)	Analysis of natural gas by trapping in acid and subsequent ICP-MS analysis using test method MT/ELE/14 - Intertek	ng/l	0.2
Manganese (Mn)			0.1
Nickel (Ni)			0.4
Phosphorous (P)			15
Selenium (Se)			0.6
Silicon (Si)			1000
Tin (Sn)			0.7
Thallium (Tl)			0.2
Vanadium (V)			0.2
Zinc (Zn)			0.6
Chromium VI (Cr VI)	Colorimetry suite - SAL	ng/l	3000
Benzene, toluene, ethylbenzene and xylenes (BTEX), Halogenated hydrocarbons and other volatile organic compounds (VOCs)	ATD/GC/MS, VOC peaks detected - SAL	mg/m ³	0.001
Total sulphur content	ASTM D6667 Total sulphur – microcoulometry (MT/ELE/11) - Intertek	µg/l	1
CV	Not applicable (n/a), data taken from continuous monitor on site	MJ/m ³	n/a
Wobbe Index	Not applicable, data taken from continuous monitor on site	n/a	n/a

5 Existing data

Although National Grid plc undertakes continuous monitoring of natural gas, this monitoring does not include most of the parameters in Table 1 (e.g. metals, BTEX and VOCs). The literature review did not identify existing datasets relating to these parameters in natural gas.

National Grid plc has provided an example of existing data from their continuous monitoring programme. This data is summarised in Table 3 and Table 4.

Table 3: Summary of data collected by National Grid plc continuous monitors over a two day period, Part 1

	Methane	Nitrogen	Ethane	Carbon dioxide	Propane	Isobutane	Butane	Pentane	Isopentane	Neopentane	Hexane	Heptane	Octane	Nonane	Decane	Undecane	Dodecane
	%	%	%	%	%	%	%	%	%	%	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Mean	92.42	3.67	3.02	0.78	0.59	0.09	0.14	0.04	0.04	0.00	409.28	540.97	184.84	14.37	0.02	1.14	0.44
Median	92.14	3.78	3.01	0.86	0.59	0.09	0.14	0.04	0.04	0.00	405.64	530.90	177.99	12.78	0.00	0.00	0.00
Minimum	90.84	2.44	2.93	0.32	0.53	0.08	0.11	0.03	0.03	0.00	355.87	492.51	150.39	7.77	0.00	0.00	0.00
Maximum	94.42	4.84	3.14	1.35	0.67	0.12	0.16	0.05	0.05	0.01	484.36	687.53	301.71	46.72	1.84	89.57	15.34
No. of samples	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119

Table 4: Summary of data collected by National Grid plc continuous monitors over a two day period, Part 2

	Total sulphur	Hydrogen sulphide	Oxygen	Hydrogen	Water	Wobbe Index	Sooting Index	Incomplete Combustion Factor
	mg/m³	mg/kg	mg/kg	mg/kg	mg/kg	-	-	-
Mean	0.52	0.36	0.00	2.27	40.90	48.53	0.47	-1.26
Median	0.52	0.36	0.00	0.00	38.80	48.35	0.47	-1.38
Min	0.44	0.31	0.00	0.00	34.80	47.54	0.45	-1.87
Max	0.57	0.40	0.00	165.00	66.80	49.70	0.50	-0.55
No. of samples	119	119	119	119	119	119	119	119

6 Primary data

6.1 Statistical analysis of data

No statistical analysis was conducted on the data as the sample number was less than ten.

6.2 Using the data tables

Data are presented in tables summarising:

- Metals including Cr VI - **Error! Reference source not found.**;
- Gas density data collected during sampling - Table 6;
- BTEX - Table 7;
- Halogenated hydrocarbons - Table 8;
- Total sulphur content, CV and Wobbe Index - Table 9 and,
- Other VOCs - **Error! Reference source not found.** to **Error! Reference source not found.** in Appendix A – VOC screen data.

We recommend comparing the concentrations of analytes in the comparators dataset to the concentrations in the waste-derived material, paying attention to the higher values in both datasets.

This comparison does not constitute a pass/fail test or an end of waste view. It will provide an indication of whether the waste material contains similar levels of analytes to non-waste materials and whether you wish to seek the view of the Environment Agency by making an end of waste application or that further analysis or improved treatment processes may be warranted.

6.3 Primary data tables

The primary data tables are shown on the following pages.

Table 5: Metals* (ng/l)

Sample ID	Sb	As	Cd	Cr VI	Cr	Co	Cu	Pb	Mn	Hg	Ni	P	Se	Si	Tl	Sn	V	Zn
Natural gas 01	<0.3	<0.5	0.3	<3000	2.4	0.2	11.2	8.4	4.9	<0.2	7.9	<12.9	<0.5	<857.8	<0.2	4.3	0.2	1415.4
Natural gas 02	<0.3	<0.5	29.7	<3000	1.7	1.1	36.6	17.4	2.7	<0.2	70.5	<12.9	<0.5	<860.1	<0.2	2.5	<0.2	283.8
Natural gas 03	0.4	<0.5	156.3	<3000	9.7	3.1	127.0	469.0	8.9	0.3	506.8	21.5	<0.5	<858.9	<0.2	9.5	0.3	996.3
Natural gas 04	<0.3	<0.5	3.1	<3000	2.2	0.1	4.4	17.3	0.8	<0.2	8.1	<13.2	<0.5	<880.2	<0.2	1.5	<0.2	35.6
Natural gas 05	<0.3	<0.5	1.1	<3000	0.9	7.2	15.3	3.4	0.5	<0.2	5.9	<13.2	<0.5	<881.9	<0.2	10.6	<0.2	27.2
Natural gas 06	<0.3	<0.5	1.7	<3000	0.4	0.1	8.6	2.0	2.8	<0.2	5.9	<13.3	<0.5	<881.6	<0.2	0.9	<0.2	77.4
Natural gas 07	<0.3	<0.5	<0.2	<3000	1.0	<0.1	3.5	0.6	0.6	<0.2	1.0	<13.8	<0.6	<917.1	<0.2	0.7	<0.2	13.8
Natural gas 08	<0.3	<0.5	0.9	<3000	13.3	0.1	8.5	11.9	1.6	<0.2	8.4	<13.8	<0.6	<920.3	<0.2	1.7	<0.2	29.4
Natural gas 09	<0.3	<0.6	0.9	<3000	0.7	<0.1	11.6	7.5	0.6	<0.2	8.9	<13.8	<0.6	<916.8	<0.2	0.7	<0.2	64.4

*metals data was reported by the laboratory in ng/g (excluding CrVI), therefore metals data has been converted to ng/l using gas density data collected during sampling (Table 6).

Table 6: Gas density data collected during sampling

Sample ID	Line Pressure	Line Density	Line Temperature	Line Temperature	Standard Pressure	Standard Temperature	Density at Standard Temperature and Pressure*
	Barg	Kg m ³	°C	K	Bar	k	Kg m ³
Natural gas 01	65.9	60.1	21.1	294.2	1.0133	273.2	0.858
Natural gas 02	65.7	60.1	21.4	294.6	1.0133	273.2	0.860
Natural gas 03	65.8	60.1	21.2	294.3	1.0133	273.2	0.859
Natural gas 04	64.3	60.3	21.6	294.8	1.0133	273.2	0.880
Natural gas 05	64.3	60.2	20.7	293.9	1.0133	273.2	0.882
Natural gas 06	64.3	60.1	18.4	291.6	1.0133	273.2	0.888
Natural gas 07	65.2	63.1	18.8	292.0	1.0133	273.2	0.917
Natural gas 08	65.2	63.3	18.7	291.9	1.0133	273.2	0.920
Natural gas 09	65.3	63.1	18.7	291.9	1.0133	273.2	0.917

* Gas density used to convert metals data from ng/g to ng/l

Table 7: BTEX, - = not detected during the VOC screen (mg/m³)

Sample ID	Benzene	Toluene	Ethylbenzene	o-Xylene
Natural gas 01	0.280	0.370	0.410	-
Natural gas 02	0.300	0.150	0.390	0.210
Natural gas 03	-	-	0.050	-
Natural gas 04	0.430	0.180	0.310	0.380
Natural gas 05	0.290	0.110	0.110	0.023
Natural gas 06	0.280	0.080	0.044	0.030
Natural gas 07	1.90	0.550	0.038	0.120
Natural gas 08	1.5	0.475	0.075	0.150
Natural gas 09	1.5	0.575	0.013	-

Table 8: Halogenated hydrocarbons, - = not detected during the VOC screen (mg/m³)

	Propane, 2,2-difluoro-	Cycloheptane, bromo-	Norflurane	2-Propanone, 1,1,1-trifluoro-
Natural gas 01	0.002	0.068	-	-
Natural gas 02	-	-	0.014	-
Natural gas 03	-	-	-	-
Natural gas 04	-	-	-	-
Natural gas 05	-	-	-	-
Natural gas 06	-	-	-	-
Natural gas 07	-	-	-	-
Natural gas 08	-	-	-	-
Natural gas 09	-	-	-	0.003

Table 9: Total sulphur[#], Calorific value and Wobbe Index

Sample ID	S	Calorific value	Wobbe Index
	mg/m³	MJ/m³	-
Natural gas 01	0.5	39.30	49.99
Natural gas 02	0.4	39.32	50.02
Natural gas 03	0.4	39.33	50.03
Natural gas 04	0.2	39.33	50.07
Natural gas 05	0.3	39.32	50.12
Natural gas 06	0.3	39.32	50.08
Natural gas 07	0.4	39.29	49.97
Natural gas 08	0.5	39.27	49.96
Natural gas 09	0.5	39.28	49.95

total sulphur content reported by the laboratory in ug/l, now converted to mg/m³

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Glossary

Calorific value (CV) – a measure of heating power, dependent upon the composition of gas. The CV refers to the amount of energy released when a known volume of gas is completely combusted under specified conditions.

Dewpoint – the atmospheric temperature (varying according to pressure and humidity) below which water droplets begin to condense and dew can form.

Incomplete Combustion Factor (ICF) – an empirical index that relates the composition of a gas to its tendency to burn incompletely in a gas appliance.

Soot Index (SI) – an empirical index that relates the composition of a gas to its tendency to produce soot during combustion in a gas appliance.

Wobbe Index – an indicator of the interchangeability of fuel gases such as natural gas, liquefied petroleum gas (LPG), and town gas. Defined as the higher CV divided by specific gravity.

List of abbreviations

As	Arsenic
ASTM	American Society for Testing and Materials
ATD/GCMS	Gas chromatography–mass spectrometry
BBL	Balgzand to Bacton Line
BGS	British Geological Survey
BTEX	Benzene, toluene, ethylbenzene and xylenes
Cd	Cadmium
Co	Cobalt
Co	Copper
Cr	Chromium
Cr VI	Chromium 6
CV	Calorific value
DECC	Department of Energy & Climate Change
EDF	Électricité de France
H ₂ S	Hydrogen sulphide
Hg	Mercury
ICF	Incomplete Combustion Factor
IC-MS	Ion chromatography mass spectrometry
LOD	Limit of detection
Mn	Manganese
n/a	not applicable
Ni	Nickel
NTS	National Transmission System
Pb	Lead
Pb	Phosphorous
SAL	Scientific Analysis Laboratories Limited
Sb	Antimony
Se	Selenium
si	Silicon
SI	Soot Index
Sn	Tin
Th	Thallium
V	Vanadium
VOC	Volatile organic compounds
Zn	Zinc

Appendix A – VOC screen data

Table 10: VOC screen (mg/m³)

Sample ID	(1-Methoxy-pentyl)-cyclopropane	(1-Propoxy-pentyl)-cyclopropane	alpha-Methylstyrene	1-(Trimethylsilyl)-1-propyne	1,1,4-Trimethylcyclohexane	1,1'-Bicycloheptyl	1,1'-Bicyclohexyl, 2-ethyl-, trans-	1,2,4,5-Tetrazin-3-amine	1,2,4-Triazine-5-ol, 3,6-dimethyl-	1,2-Dipropylcyclopropane	1,2-Ethanediamine, N,N'-diethyl-	1,3,5,7-Cyclooctatetraene	1,3-Cyclopentadiene, 5-(1-methylpentylidene)-	1,3-Dimethyl cyclopentane	1,3-Hexadiene, 3-ethyl-2,5-dimethyl-	1,4-Benzenedicarboxylic acid, dimethyl ester	1-Butanamine, 2-methyl-N-(2-methylbutylidene)-	1-Butanol	1-Butanol, 2-ethyl-
Natural gas 01	-	-	-	-	-	-	-	-	-	-	-	-	0.001	0.150	-	0.002	-	-	-
Natural gas 02	0.006	-	0.002	-	-	-	0.010	0.019	-	-	0.004	0.010	-	-	-	-	0.013	0.025	-
Natural gas 03	-	0.037	-	-	0.020	0.001	0.007	-	-	0.005	-	-	-	-	-	-	-	-	-
Natural gas 04	-	-	-	0.019	-	-	-	-	-	-	-	-	-	0.150	-	-	-	-	0.032
Natural gas 05	-	-	-	-	0.024	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Natural gas 06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Natural gas 07	-	-	-	-	0.135	-	-	-	-	-	-	-	-	0.775	-	-	-	-	-
Natural gas 08	-	-	-	-	0.148	-	-	-	-	-	-	-	-	0.800	-	-	-	-	-
Natural gas 09	-	-	-	-	0.203	-	-	-	-	0.017	-	-	-	0.525	0.003	-	-	-	-

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Table 11: VOC screen (mg/m³)

Sample ID	1-Ethyl-2,6-trimethylcyclohexane	1-Ethyl-3-methylcyclohexane (c,t)	1-Ethyl-4-methylcyclohexane	1-Hexanol, 2-ethyl-	1H-Imidazole, 4,5-dihydro-2-methyl-	1H-Imidazole-4-carboxamide, 5-amino-	1H-Indene, octahydro-, cis-	1-Methoxy-6,6-dimethyl-cyclohex-2-ene	1-Methyl-2-methylenecyclohexane	1-Methylcyclooctene	1-Octene	1-Penten-3-one	1-Pyrrolidinecarboxaldehyde	1R,2c,3t,4t-Tetramethyl-cyclohexane	2(3H)-Furanone, 5-ethylidihydro-	2(5H)-Furanone, 5-(1-methylethyl)-	2,3-Dimethylpentane	2,4,6-Octatriene, 2,6-dimethyl-	2,4,6-Trimethyl-1,5-diazabicyclo[3.1.0]hexane	2,4-Imidazolidinedione, 5,5-dimethyl-	
Natural gas 01	-	-	-	-	-	0.004	0.003	-	-	-	-	0.055	-	-	-	-	-	-	-	-	0.019
Natural gas 02	0.001	0.016	-	-	-	-	0.011	-	-	-	-	-	-	-	0.055	-	-	0.001	0.002	-	-
Natural gas 03	-	0.013	-	-	-	-	-	0.002	-	0.009	-	-	0.006	0.005	-	-	-	-	-	-	-
Natural gas 04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.220	-	-	-	-
Natural gas 05	-	-	-	-	-	-	0.002	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Natural gas 06	-	-	-	0.001	0.025	-	-	-	-	0.006	-	-	-	-	-	-	-	-	-	-	-
Natural gas 07	-	-	-	0.004	-	-	-	-	0.003	-	0.425	-	-	-	-	0.048	-	-	-	-	-
Natural gas 08	-	-	0.090	0.003	-	-	-	-	0.003	0.020	-	-	-	-	-	-	-	-	-	-	-
Natural gas 09	-	0.083	-	-	-	-	-	-	-	0.021	0.375	-	-	-	-	-	-	-	-	-	-

Table 12: VOC screen (mg/m³)

Sample ID	2-Aminocyanacetamide	2-Butanone, 4-(dimethylamino)-	2-Cyclohexen-1-ol, 2-methyl-5-(1-methylethenyl)-, acetate	2-Cyclohexen-1-one, 3,5-dimethyl-	2-Heptene	2-Methylbutane	2-Methylheptane	2-Methylpentane	2-Octen-4-ol, 2-methyl-	2-Pentene, 2,4,4-trimethyl-	2-Pentene, 3,4,4-trimethyl-	2-Pentene, 3-ethyl-	2-Propanone, 1,1,1-trifluoro-	2-Pyrazoline, 1-isopropyl-5-methyl-	2-Pyrrolidinone	2-Undecen-4-ol	3-(1'-pyrrolidinyl)-2-butanone	3,7-Decadiene, 2,9-dimethyl-	3-Butene-1,2-diol, 1-(2-furanyl)-	3-Carene
Natural gas 01	-	-	0.003	-	-	-	-	-	-	-	-	-	-	0.075	-	-	-	-	-	-
Natural gas 02	0.015	0.001	-	-	0.052	-	-	0.300	-	-	0.017	-	-	0.083	-	-	-	-	0.001	-
Natural gas 03	-	-	-	0.001	-	-	-	-	-	-	-	-	-	-	-	0.001	0.007	0.004	-	-
Natural gas 04	-	-	-	-	-	0.190	-	0.980	-	0.008	-	-	-	0.049	0.006	-	-	-	-	-
Natural gas 05	-	-	-	-	-	-	-	0.420	-	-	-	-	-	-	-	-	-	-	-	-
Natural gas 06	-	-	-	-	-	-	-	0.660	-	-	-	0.023	-	-	-	-	-	-	-	-
Natural gas 07	-	-	-	-	-	0.750	0.425	2.500	-	-	-	-	-	-	-	-	-	-	-	0.003
Natural gas 08	-	-	-	-	-	0.600	0.750	2.750	0.008	-	-	-	-	-	-	-	-	-	-	-
Natural gas 09	-	-	-	-	-	0.775	0.350	2.375	-	-	-	-	0.003	-	-	-	-	-	-	-

Table 13: VOC screen (mg/m³)

Sample ID	3-Ethoxyacrylonitrile	3H-1,2,4-Triazol-3-one, 1,2-dihydro-	3-Heptyne, 5-methyl-	3-Hexanone	3-Hexanone, 2,5-dimethyl-	3-Hexanone, 2-methyl-	3-Hexene, 1-methoxy-, (Z)-	3-Hexene-2,5-dione	3-Methyl heptane	3-Pentanone, 2,4-dimethyl-	4,4'-Bi-1,3,2-dioxaborolane, 2,2'-diethyl-	4-Methoxy-3-buten-2-one	4-Methyloctane	4-Octen-3-one	4-Piperidinamine, N,1-dimethyl-	5-Diazo-1,3-cyclopentadiene	Acetone	Aziridine, 2,2-dimethyl-	Aziridine, 2,3-dimethyl-1-(phenylmethyl)-, trans-	Benzaldehyde, 2-methyl-
Natural gas 01	-	0.068	-	-	-	-	-	0.055	-	0.048	0.015	-	-	-	0.003	0.002	-	0.100	-	0.002
Natural gas 02	-	-	-	-	-	0.046	-	-	-	-	-	-	-	-	-	-	-	-	0.017	0.001
Natural gas 03	-	-	0.002	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Natural gas 04	-	-	-	0.013	-	-	-	-	-	-	-	-	0.058	-	-	-	-	-	-	-
Natural gas 05	0.002	-	-	-	-	-	-	-	-	-	-	-	0.004	-	-	-	0.010	-	-	-
Natural gas 06	-	-	-	-	-	-	-	-	-	-	-	0.001	-	-	-	-	0.006	-	-	-
Natural gas 07	-	-	-	-	0.003	-	-	-	-	-	-	0.045	-	-	-	-	-	-	-	-
Natural gas 08	-	-	-	-	-	-	-	-	0.350	-	-	-	-	-	-	-	-	-	-	-
Natural gas 09	-	-	-	-	-	-	0.095	-	-	-	-	-	-	0.040	-	-	-	-	-	-

Table 14: VOC screen (mg/m³)

Sample ID	Benzaldehyde, 3-methyl-	Benzaldehyde, 4-methyl-	Benzene	Benzene, (1,1-dimethylpropyl)-	Benzene, (1-methylbutyl)-	Benzene, (1-methylethyl)-	Benzene, 1,2,3-trimethyl-	Benzene, 1,2,4-trimethyl-	Benzene, 1,2-diethyl-	Benzene, 1,3,5-trimethyl-	Benzene, 1,3-diethyl-	Benzene, 1,3-dimethyl-	Benzene, 1-ethyl-2,4-dimethyl-	Benzene, 1-ethyl-2-methyl-	Benzene, 1-ethyl-3,5-dimethyl-	Benzene, 1-ethyl-3-methyl-	Benzene, 1-ethyl-4-methyl-	Benzene, 1-methyl-3-(1-methylethyl)-	Benzene, 1-methyl-3-propyl-	Benzene, 1-methyl-4-(1-methylethyl)-
Natural gas 01	0.002	-	0.280	0.001	0.001	0.039	0.009	-	0.002	-	0.003	0.220	0.002	0.004	0.002	-	0.010	-	0.005	-
Natural gas 02	-	0.001	0.300	-	-	0.038	0.007	0.005	0.001	-	-	-	-	0.003	-	-	0.007	0.002	-	-
Natural gas 03	-	-	-	-	-	0.004	0.003	0.003	-	-	-	0.081	-	0.003	-	-	0.002	0.002	-	-
Natural gas 04	-	-	0.430	-	-	0.015	0.003	0.002	-	-	-	-	-	0.001	-	-	0.002	-	-	-
Natural gas 05	-	-	0.290	-	-	-	-	0.001	-	-	-	-	-	-	-	-	-	-	-	-
Natural gas 06	-	-	0.280	-	-	-	0.002	-	-	-	-	-	-	-	-	0.001	-	0.001	-	-
Natural gas 07	-	-	1.900	-	-	0.007	0.008	-	-	0.008	-	-	-	0.003	-	-	0.005	-	-	0.004
Natural gas 08	-	-	1.500	-	-	0.006	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Natural gas 09	-	-	1.475	-	-	0.003	-	0.004	-	-	-	-	-	-	-	-	0.003	-	-	-

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Table 15: VOC screen (mg/m³)

Sample ID	Benzene, 1-methyl-4-(1-methylpropyl)-	Benzene, 1-methyl-4-propyl-	Benzene, 2-ethyl-1,4-dimethyl-	Benzene, 4-ethenyl-1,2-dimethyl-	Benzene, propyl-	Benzene, tert-butyl-	Bicyclo[2.2.2]octane, 2-methyl-	Butane, 2-methyl-	Butanenitrile, 4-(dimethylamino)-	Camphene	cis-1-Ethyl-3-methyl-cyclohexane	cis-p-Mentha-2,8-dien-1-ol	Creatinine	Cyclobutane, methyl-	Cyclobutanone, 2,2,3-trimethyl-	Cyclobutene, 2-propenylidene-	Cycloheptane, bromo-	Cyclohexane	Cyclohexane, (1-methylethyl)-	Cyclohexane, 1,1,2,3-tetramethyl-
Natural gas 01	0.003	0.004	0.002	0.002	0.008	0.002	-	-	-	-	-	-	-	0.087	0.094	0.001	0.068	0.430	-	0.008
Natural gas 02	-	0.003	-	0.001	0.005	0.004	-	-	-	-	-	0.002	-	-	0.120	-	-	0.300	-	0.020
Natural gas 03	-	-	-	-	0.002	0.005	-	-	0.003	-	-	-	0.003	-	-	-	-	-	-	0.019
Natural gas 04	-	0.001	-	-	0.002	0.002	-	-	-	-	-	-	-	-	-	-	-	0.370	0.005	-
Natural gas 05	-	-	-	-	-	0.002	-	0.160	-	-	-	-	-	-	-	-	-	0.390	-	-
Natural gas 06	-	-	-	-	-	0.002	0.001	0.066	-	-	-	-	-	-	-	-	-	0.560	-	0.002
Natural gas 07	-	-	-	-	0.003	0.008	-	-	-	0.008	0.088	-	-	-	-	-	-	2.100	0.033	0.013
Natural gas 08	-	-	-	-	-	0.004	-	-	-	-	-	-	-	-	-	-	-	1.725	0.030	-
Natural gas 09	-	-	-	-	-	0.005	-	-	-	-	-	-	-	-	-	-	-	2.075	-	-

Table 16: VOC screen (mg/m³)

Sample ID	Cyclohexane, 1,1,3,5-tetramethyl-, cis-	Cyclohexane, 1,1,3-trimethyl-	Cyclohexane, 1,1-dimethyl-	Cyclohexane, 1,2,3-trimethyl-	Cyclohexane, 1,2,3-trimethyl-, (1.alpha.,2.beta.,3.alpha.)-	Cyclohexane, 1,2,4-trimethyl-, (1.alpha.,2.beta.,4.beta.)-	Cyclohexane, 1,2-dieethyl-, cis-	Cyclohexane, 1,2-dimethyl-, trans-	Cyclohexane, 1,3,5-trimethyl-	Cyclohexane, 1,3-dimethyl-	Cyclohexane, 1,3-dimethyl-, cis-	Cyclohexane, 1,3-dimethyl-, trans-	Cyclohexane, 1,4-dimethyl-	Cyclohexane, 1,4-dimethyl-, cis-	Cyclohexane, 1,4-dimethyl-, trans-	Cyclohexane, 1-ethyl-1-methyl-	Cyclohexane, 1-ethyl-2,3-dimethyl-	Cyclohexane, 1-ethyl-2-methyl-	Cyclohexane, 1-ethyl-2-methyl-, cis-	Cyclohexane, 1-ethyl-2-propyl-
Natural gas 01	-	-	0.042	-	-	-	-	-	-	-	-	-	-	0.027	-	0.002	0.005	-	-	
Natural gas 02	0.010	-	-	-	-	0.002	-	-	-	-	-	0.013	-	0.087	-	-	-	-	-	
Natural gas 03	0.012	-	-	-	-	-	-	0.077	-	-	-	-	-	-	-	-	-	-	-	
Natural gas 04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Natural gas 05	-	-	0.032	-	-	-	-	-	-	-	-	0.055	-	0.016	-	0.002	-	-	0.003	
Natural gas 06	-	0.028	-	-	-	0.003	-	-	-	0.028	0.033	0.048	-	-	-	-	-	-	0.006	
Natural gas 07	-	-	-	0.018	-	0.030	-	-	0.093	-	0.350	0.275	-	0.248	-	-	-	-	-	
Natural gas 08	0.007	-	0.188	0.020	0.038	-	-	0.104	-	-	-	-	-	0.158	-	-	-	-	0.011	
Natural gas 09	0.007	-	-	0.022	0.033	-	-	0.225	-	0.300	-	-	-	0.195	-	0.168	-	-	-	

Table 17: VOC screen (mg/m³)

Sample ID	Cyclohexane, 1-ethyl-4-methyl-, cis-	Cyclohexane, 1-ethyl-4-methyl-, trans-	Cyclohexane, 1-methyl-2-propyl-	Cyclohexane, 1-methyl-4-(1-methylethenyl)-, cis-	Cyclohexane, 1-methyl-4-(2-hydroxyethyl)-	Cyclohexane, butyl-	Cyclohexane, ethyl-	Cyclohexane, methyl-	Cyclohexane, pentyl-	Cyclohexane, propyl-	Cyclohexane	Cyclohexene, 4-methyl-1-(1-methylethyl)-	Cyclohexene, 1-propyl-	Cyclohexene, 3-propyl-	Cyclooctane, (1-methylpropyl)-	Cyclopentane, (1,1-dimethylethyl)-	Cyclopentane, 1,2,4-trimethyl-	Cyclopentane, 1,3-dimethyl-, cis-	Cyclopentane, 1,3-dimethyl-, trans-
Natural gas 01	-	-	-	-	-	-	-	-	0.002	0.015	-	0.004	-	-	-	-	-	-	-
Natural gas 02	-	-	0.002	0.011	-	0.005	0.190	-	-	0.047	-	-	-	-	-	-	-	0.048	-
Natural gas 03	0.013	0.026	0.003	0.009	0.010	0.004	0.068	-	-	0.056	-	-	-	0.003	-	-	-	-	-
Natural gas 04	-	-	-	-	-	-	0.170	0.460	-	0.010	-	-	-	-	-	0.026	-	-	-
Natural gas 05	-	0.011	-	-	-	-	-	-	-	0.009	-	-	0.002	-	-	-	-	0.100	0.110
Natural gas 06	-	-	-	-	-	0.001	-	0.150	-	0.013	-	0.001	-	-	-	-	-	-	-
Natural gas 07	0.050	-	-	0.003	-	0.005	0.240	1.575	-	0.078	-	0.008	0.018	0.003	-	-	-	-	-
Natural gas 08	-	0.054	-	-	-	-	0.253	1.475	-	0.072	0.003	-	-	-	-	-	0.275	-	-
Natural gas 09	0.057	-	-	-	-	-	0.250	1.275	-	0.080	-	0.008	-	-	-	-	0.300	-	-

Table 18: VOC screen (mg/m³)

Sample ID	Cyclopentane, 1-ethyl-2-methyl-, cis-	Cyclopentane, ethyl-	Cyclopentane, methyl-	Cyclopentene, 1,5-dimethyl-	Cyclopentene, 3-ethyl-	Cyclopentene, 4,4-dimethyl-	Decane	Decane, 2-methyl-	Decane, 3-methyl-	Decane, 4-methyl-	Decane, 5-methyl-	D-Limonene	Dodecane	Endo-2-Methylbicyclo[3.3.1]nonane	Ethanone, 1-(1-methylcyclohexyl)-	Ethylbenzene	Furan, 2,5-dihydro-2,2,4-trimethyl-	Heptane	Heptane, 2,2,4-trimethyl-	Heptane, 2,2-dimethyl-
Natural gas 01	-	-	-	-	-	-	-	-	-	0.003	-	0.004	-	-	-	0.410	0.043	0.094	-	-
Natural gas 02	-	0.140	-	-	-	-	0.012	-	-	-	-	0.005	0.003	-	-	0.390	-	-	-	-
Natural gas 03	-	-	-	-	-	-	-	-	-	-	-	0.004	0.002	-	0.009	0.050	-	-	-	-
Natural gas 04	-	-	-	-	-	-	0.009	-	0.001	-	-	-	0.002	-	-	0.310	-	0.490	-	-
Natural gas 05	-	0.066	-	-	-	-	0.007	-	-	0.001	0.003	-	0.001	-	0.001	0.110	-	0.280	-	0.013
Natural gas 06	0.031	0.049	-	-	-	-	0.008	0.001	-	-	-	0.002	0.001	-	-	0.044	-	0.400	0.003	0.030
Natural gas 07	-	0.275	2.450	-	-	0.450	0.033	0.003	-	0.003	-	0.007	0.004	-	-	0.038	-	1.275	-	0.083
Natural gas 08	-	0.275	3.000	0.450	0.035	-	0.016	-	-	0.003	-	0.003	-	-	-	0.075	-	1.000	0.016	0.083
Natural gas 09	-	0.275	2.250	-	-	0.025	0.021	-	-	-	-	-	-	0.005	-	0.013	-	1.300	-	0.075

Table 19: VOC screen (mg/m³)

Sample ID	Heptane, 2,3-dimethyl-	Heptane, 2,4,6-trimethyl-	Heptane, 2,5-dimethyl-	Heptane, 2,6-dimethyl-	Heptane, 3,3-dimethyl-	Heptane, 3,4,5-trimethyl-	Heptane, 3-ethyl-	Heptane, 3-ethyl-2-methyl-	Heptane, 3-methyl-	Heptane, 4-(1-methylethyl)-	Heptane, 4-ethyl-	Heptane, 5-ethyl-2-methyl-	Hexane	Hexane, 2,2,4-trimethyl-	Hexane, 2,2,5-trimethyl-	Hexane, 2,3,3-trimethyl-	Hexane, 2,2-dimethyl-	Hexane, 2,4,4-trimethyl-	Hexane, 2,5-dimethyl-	Hexane, 3,3-dimethyl-	
Natural gas 01	-	-	-	-	-	0.041	-	-	-	-	-	-	0.620	-	-	-	-	-	-	-	-
Natural gas 02	-	-	-	-	-	-	-	-	-	-	-	-	0.370	-	-	-	-	-	-	-	-
Natural gas 03	-	-	-	-	-	-	0.025	-	-	-	-	0.008	-	-	-	-	-	-	-	-	-
Natural gas 04	-	0.009	0.053	-	-	-	-	-	-	-	-	-	1.000	-	-	-	-	-	-	-	-
Natural gas 05	0.020	0.004	0.031	-	-	-	-	0.002	-	-	-	-	0.840	-	-	-	-	-	0.009	-	-
Natural gas 06	0.029	0.003	-	0.062	0.008	-	-	-	-	0.002	0.020	-	0.640	-	0.031	0.100	-	-	-	0.003	-
Natural gas 07	0.120	0.045	0.153	-	0.003	-	-	0.019	-	-	0.043	-	1.225	-	-	0.004	-	-	-	-	0.100
Natural gas 08	0.114	0.026	0.152	-	-	-	-	0.016	-	-	-	-	2.750	-	-	-	-	-	0.038	-	0.105
Natural gas 09	0.110	-	0.160	-	-	-	-	0.014	0.110	-	-	-	1.450	0.053	-	0.068	-	-	0.030	-	0.080

Table 20: VOC screen (mg/m³)

Sample ID	Hexane, 3-ethyl-	Hexane, 3-ethyl-2-methyl-	Hexane, 3-methyl-	Isobutane	L-alpha-Terpineol	Limonene	Longifolene	m+p-Xylene	Mesitylene	Methylcyclohexane	methylcyclopentane	m-Menthane, (1S,3R)-(+)-	m-Menthane, (1S,3S)-(+)-	Nanofin	Naphthalene, 1,2,3,4-tetrahydro-	Naphthalene, decahydro-, trans-	Nonane	Nonane, 2,6-dimethyl-	Nonane, 2-methyl-	Nonane, 3-methyl-
Natural gas 01	-	-	-	-	0.003	-	0.002	-	0.005	0.670	-	-	0.002	-	0.001	0.002	-	-	-	-
Natural gas 02	-	-	-	-	0.003	-	0.001	-	-	0.280	0.380	0.007	-	-	0.002	-	-	-	-	-
Natural gas 03	-	-	-	-	0.002	-	-	-	-	-	-	-	0.005	0.013	-	0.003	0.020	-	-	-
Natural gas 04	-	-	-	-	-	-	0.002	0.760	-	-	-	-	-	-	-	-	-	-	0.002	0.003
Natural gas 05	-	-	0.026	0.004	-	-	-	0.160	-	0.320	0.460	-	-	-	-	-	0.063	-	-	0.003
Natural gas 06	-	-	0.320	-	0.002	-	-	0.078	0.002	-	0.260	-	-	-	-	-	0.047	0.002	-	0.002
Natural gas 07	0.113	0.028	-	-	0.005	-	-	0.118	-	-	-	-	-	-	-	-	0.215	0.007	-	0.010
Natural gas 08	-	-	-	-	-	-	-	0.234	0.003	-	-	-	-	-	-	-	0.228	-	-	0.006
Natural gas 09	-	-	-	-	0.004	0.003	-	0.075	0.003	-	-	-	-	-	-	-	0.188	-	-	-

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Table 21: VOC screen (mg/m³)

Sample ID	Nonane, 4-methyl-	Nonane, 5-methyl-	Norflurane	Octane	Octane, 2,3-dimethyl-	Octane, 2,5-dimethyl-	Octane, 2,6-dimethyl-	Octane, 2,7-dimethyl-	Octane, 2-methyl-	Octane, 3,3-dimethyl-	Octane, 3,5-dimethyl-	Octane, 3-ethyl-	Octane, 3-methyl-	Octane, 4-methyl-	o-Cymene	o-Xylene	p-Cymene	Pentane, octahydro-	Pentane, octahydro-, cis-	Pentane
Natural gas 01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.004	-	0.003	-	-	-
Natural gas 02	0.011	-	0.014	-	-	-	-	-	-	-	-	0.009	-	0.170	0.003	0.210	-	-	-	
Natural gas 03	-	-	-	-	-	-	0.020	-	-	0.012	-	-	-	-	-	-	-	-	0.006	-
Natural gas 04	0.003	-	-	0.310	-	-	-	-	0.053	0.002	-	-	-	-	-	0.380	-	-	-	0.320
Natural gas 05	0.003	0.001	-	0.210	-	-	-	0.002	0.045	0.001	-	-	0.089	0.018	-	0.023	-	-	-	0.260
Natural gas 06	0.003	-	-	0.130	0.002	0.003	0.003	-	-	0.001	0.002	-	-	0.030	-	0.030	-	-	-	0.260
Natural gas 07	-	0.004	-	0.925	-	-	-	-	0.198	0.009	-	-	0.190	0.110	0.008	0.120	-	0.033	-	2.450
Natural gas 08	0.026	0.003	-	0.650	-	-	0.026	0.007	-	0.008	-	-	0.174	0.113	-	0.150	-	-	0.035	2.750
Natural gas 09	0.011	-	-	0.775	-	-	0.025	-	-	0.008	-	-	0.170	0.105	-	-	-	-	-	2.500

Table 22: VOC screen (mg/m³)

Sample ID	Pentane, 2,2-dimethyl-	Pentane, 2,3,3,4-tetramethyl-	Pentane, 2,3-dimethyl-	Pentane, 3,3-dimethyl-	Pentane, 3-ethyl-	Pentane, 3-ethyl-2,2-dimethyl-	Pentanoic acid, 1,1-dimethylpropyl ester	Piperidine, 1-(1-methylpentyl)-	Propane, 2,2-difluoro-	Propanoic acid, 2-methyl-, anhydride	Propionaldehyde, diethylhydrazone	p-Xylene	Pyridine, 4-ethenyl-	Pyrimidine, 4-amino-2-methoxy-	Pyrrolidine	Succinimide	Sulfur dioxide	Thiazole, 2-methyl-	Toluene	trans-1,2-Diethyl cyclopentane
Natural gas 01	-	-	-	-	-	-	-	0.005	0.002	0.033	-	-	-	-	-	0.004	-	0.370	-	
Natural gas 02	-	-	-	-	0.008	-	0.054	-	-	-	0.019	-	0.048	0.002	0.021	0.018	0.002	0.002	0.150	-
Natural gas 03	-	-	-	-	-	-	-	-	-	-	-	0.044	-	-	-	-	-	-	-	-
Natural gas 04	-	0.065	-	-	-	-	-	-	-	-	-	-	-	-	0.043	-	-	-	0.180	-
Natural gas 05	0.026	-	-	0.020	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.110	0.029
Natural gas 06	-	-	0.074	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.080	-
Natural gas 07	-	-	-	0.325	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.550	-
Natural gas 08	-	-	-	0.275	-	0.154	-	-	-	-	-	-	-	-	-	-	-	-	0.475	-
Natural gas 09	-	-	-	0.350	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.575	-

Table 23: VOC screen (mg/m³)

Sample ID	Trans-1,4-diethylcyclohexane	Tridecane	Undecane	Uracil, 1-methyl-	Vinyl butyrate
Natural gas 01	-	-	0.010	0.011	-
Natural gas 02	-	0.001	0.006	-	-
Natural gas 03	0.002	0.001	0.005	-	-
Natural gas 04	-	-	0.004	-	-
Natural gas 05	-	-	0.003	-	0.003
Natural gas 06	-	-	0.004	-	-
Natural gas 07	-	0.004	0.011	-	-
Natural gas 08	-	-	0.005	-	-
Natural gas 09	-	-	0.006	-	-

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