Risk assessment of biogas in kitchens

Carole Leroux, Hugues Modelon, Christophe Rousselle, Gaël Bellenfant, Olivier Ramalho, Jean-Paul Jaeg, Isabelle Zdanevitch, Ghinwa M. Naja

Risk assessment of biogas exposure in kitchens

C. Leroux[1*], H. Modelon[1], C. Rousselle[1], G. Bellenfant[2], J.P. Jaeg[3], O. Ramalho[4], I. Zdanevitch[5], G. Naja[6]

1: French Agency for Environmental and Occupational Health Safety, Maisons-Alfort, France
2: BRGM, Orléans, France
3: National Veterinary School, Toulouse, France
4: Scientific and Technical Center for Building, Marne-la-Vallée, France
5: National Institute for Industrial Environment and Risks, Verneuil-en-Halatte, France
6: Everglades Foundation, Miami, Florida, USA and McGill University, Montreal, Quebec, Canada

**Corresponding email: carole.leroux@afsset.fr*

SUMMARY

The health risk associated with human exposure to pollutants while using biogas for cooking was assessed following the methodology described by the US - National Research Council. Information of hazardous compounds and compositions of several biogas types were extracted from scientific literature. Compositions were dependent on the biogas origin (production process). First, a quantitative approach was conducted to identify substances with a high health risk based on their Human Toxicity Values. Then, a subsequent qualitative analysis was performed to complete the health risk assessment based on other toxicology data, effectiveness of purification processes, variability of the waste materials used for biogas generation and, when possible, a comparison with natural gas. The main conclusion of the study was that the injection in the grid of upgraded biogas originating from household and organic waste landfills, did not present an increase of health risks when compared to the domestic use of natural gas.

KEYWORDS

Biogas, risk assessment, human toxicity values, waste, valuable energy

INTRODUCTION

Biogas, a combustible gas mainly composed of methane and carbon dioxide, is produced by the anaerobic decomposition of organic matter (or methanisation). It could be used as a valuable energy source for heat or electricity production or, upon further purification, as a fuel vehicle. In some countries it can also be injected in the network. In France, the Ministries of Health and Ecology needed to establish the biogas risks to public health, to the environment or to the safety of facilities before authorising the biogas injection into the gas distribution grid. In September 2006, these ministries requested the French Agency for Environmental and Occupational Health Safety (Afsset) to provide a risk assessment of the potential health hazards associated with the biogas (and its combustion residues) when used for domestic cooking (Afsset, 2008). This health risk assessment was performed by a multidisciplinary working group that applied the methodology described by the US - National Research Council (National Research Council, 1983). It includes the following steps: 1) identification of compounds of interest; 2) hazard identification; 3) dose-response assessment; 4) exposure assessment for the relevant population and 5) risk characterization. Quantitative and qualitative analyses of biogas were performed and all compounds, identified as components of the biogas, were carefully studied taking into account the effectiveness of biogas processing, the variability of waste raw materials and, whenever possible, the natural gas composition.

METHODS

Data obtained from scientific literature (review until August 2007) was used to establish theoretical compositions of combustion residues and several biogas types as outlined in the Figure 1.

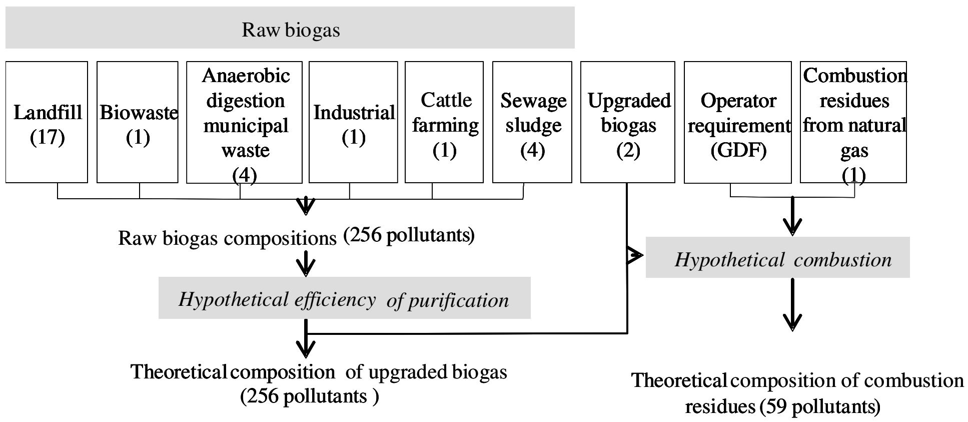

Figure 1 : Theoretical chemical composition of the biogas based on data from scientific literature. Numbers between brackets are the number of bibliographic references. GDF (Gaz de France) is the main private company delivering natural gas to users.

At least 31 publications reporting analytical composition of biogas were identified. Mainly for biogas produced in France. Because of country specificities, European and international data were often used for discussion and comparison.

The pollutants emitted while using biogas in a kitchen under normal conditions were identified. The characteristics of the biogas emission during the ignition phase (the stove is switched on) and the cooking phase are listed in Table 1. A mass balance model was used to predict the exposure concentrations of these identified pollutants while using the biogas during the ignition phase and during the cooking phase in a typical kitchen. The following assumptions were made to determine the exposure concentrations of domestic home users: the gas reaching homes was 100 % biogas (no mixing with natural gas) and the stove is the only source of pollutant emission.

Table 1 : Characteristics of biogas emission

	Ignition phase	**Cooking phase**
Duration	5-seconds	1-hour
Gas flow rate	$0.3\ m^3 \cdot h^{-1}$	$0.15\ m^3 \cdot h^{-1}$
Ventilation rate	Varying between 0.5 – 1 and 3 volume h^{-1}	
Use of the stove	Twice a day every 7 hours	
Room characteristics	$7\ m^2$ area, $17\ m^3$ volume	

Compounds from the biogas analytical composition were classified along with their Human Toxicity Values (HTV) as established by selected national and international organizations (Agency for Toxic Substances and Disease Registry ATSDR, Health Canada, Office of Environmental Health Hazard Assessment OEHHA, Dutch National Institute for Public Health and the Environment RIVM, US-Environmental Protection Agency EPA and World Health Organization WHO). Only inhalation exposure concentrations were considered relevant for the present issue.

A health risk assessment was conducted based on these toxicology data available for each identified chemical compound. A quantitative analysis was first performed on compounds for which HTVs are available to calculate the risk indicators. For chemicals with threshold levels, Hazard Quotients (HQ) were calculated and discussed for acute and chronic exposure. For chemicals without threshold levels, an excess lifetime risks, based on a linear dose-response relationship at low dose simplistic assumption, were calculated for chronic exposure.
A qualitative analysis was then conducted for compounds for which HTVs are not available, based on other toxicology data from the bibliography.

RESULTS

The analytical chemical composition has confirmed that the biogas main components, methane and carbon dioxide, constituted over 50 % (biogas from landfill) and up to 90 % (biogas from digester) of the untreated biogas. The other main components were water, hydrogen sulphide, oxygen and nitrogen. In addition, ~250 and ~60 various chemical contaminants were identified in different biogas types and in their combustion residues, respectively. These compounds, accounting for less than 5 % of untreated biogas, belong to several chemical families such as organohalides, polycyclic and monocyclic aromatic hydrocarbons, metals, aldehydes, alkanes, alcohols, esters, alkenes, sulphur compounds and ethers.

Chronic HTVs were found for 40 % of 250 identified compounds (considering all biogases sources) and acute HTVs were found for 15 %. For acute exposure, only hydrogen sulphide was determined above the acceptable threshold in raw biogas. Table 2 summarizes results for chronic exposure to compounds for which a health risk could not be ruled out in the first approach. HQ values > 1 mean that a toxic effect may occur. In this study, an excess lifetime risk (ER) < 1.10^{-6} was chosen as an acceptable value for cancer risk estimation.

Table 2 : Quantitative assessment results for chronic exposure

Biogas origin	Ignition		Combustion	HTV	
	Raw landfill and digester	Upgraded-landfill	Residues natural gas[1]	Organisation	Last revised
Hydrogen sulphide (HQ)	<2 -5	0		US EPA	2003
Formaldehyde (ER)	n/i – 4.10^{-6}	n/i	2.10^{-5}	US EPA	2002
Acetaldehyde (ER)	n/i – 3.10^{-6}	n/i		OEHHA	2002
Vinyl chloride (ER)	6.10^{-9} – 3.10^{-5}	n/i		OEHHA	2002
Trichloroethylene (ER)	<1.10^{-6} – 1.10^{-6}	2.10^{-10}		OEHHA	2002
Tetrachloroethylene (ER)	<2.10^{-6} – 6.10^{-6}	3.10^{-10}		OEHHA	2002
Tetrachloromethane (ER)	<5.10^{-10}- 4.10^{-6}	n/i		OEHHA	2002
1,4 dichlorobenzene (ER)	<2.10^{-7}– 4.10^{-6}	6.10^{-9}		OEHHA	2002
Benzene (ER)	<3.10^{-7} – 5.10^{-5}	n/i	1.10^{-6}	OEHHA	2002
Arsenic (ER)			3.10^{-5}	US EPA	1998
Cadmium (ER)			1.10^{-5}	OEHHA	2002
Chromium (ER)	6.10^{-6}– <7.10^{-5}	n/i	5.10^{-4}	OEHHA	2002
Nickel (ER)			1.10^{-6}	WHO	2000

n/i: no information ; MRL: Minimal Risk Level; HQ: Hazard Quotient ; ER: Excess Risk
1: Compounds in this column are not specific to biogas. Data originates from combustion residues in boilers and burners (in France and the USA).

DISCUSSION

Ignition phase:

Acute exposure in the kitchen: The different biogas types did not present any hazard above the acceptable threshold level except for the hydrogen sulphide in the untreated biogas. The risk for this compound was not relevant in the treated biogas (HQ < 1).
Chronic exposure in the kitchen: Hydrogen sulphide, acetaldehyde, formaldehyde, some organic chlorine derivatives, benzene and chromium were identified as potentially hazardous compounds in the untreated biogas. However, knowing the chemical composition of purified biogas, the efficiency of the treatment and purification to attain the technical specifications for the biogas injection and considering the progress in sorting waste and in regulations dealing with waste management, the health risks related to the exposure to these compounds in the purified biogas during the ignition phase were sufficiently reduced and eliminated.

Cooking phase and combustion residues:
The main biogas combustion products were not different from the natural gas combustion products currently supplied (similar composition of main components and same calorific value). The main pollutants that might be emitted were nitrogen oxides, carbon monoxide and unburned components (volatile organic components, particles, etc.).
For formaldehyde, the assessment based on the Afsset recommendation for reference level for indoor air assessment leads to a HQ of 0.1 (Afsset, 2007).
Risk assessment related to the combustion of purified biogas: Based on the exposure hypothesis assumed, no risks were identified.
Risk assessment related to the combustion of untreated biogas and natural gas: Metals (arsenic, chromium, nickel, and cadmium), formaldehyde and benzene were the main substances likely to be hazardous during chronic exposure to combustion products of both natural gas and biogas.

CONCLUSIONS
Given the available data and the conclusions of the experts, the injection of certain types of purified biogas into the gas grid does not present additional health risks for users before and after combustion, compared to natural gas as currently supplied. This covers the upgraded biogas from household waste and similar sources produced in facilities for storing non-dangerous waste such as fermentation of non-dangerous waste in a digester (sorted bio-waste or household waste; organic waste from farms, catering waste and fermentable organic waste from the agri-food industry). However, the experts did not conclude on biogas from sewage treatment plant or industrial wastes other than fermentable organic waste from the agri-food industries. Given the great variability of these industries, the available data today were not sufficient to allow a satisfactory health risk assessment.

ACKNOWLEDGEMENT
The authors acknowledge the active participation of the other members of the Working Group: R. Alary, P. Bajeat, J.J. Godon, G. Keck, A. Lattes, M. Moletta-Denat and S. Wenisch.

REFERENCES
AFSSET. 2008. Evaluation des risques sanitaires liés à l'injection de biogaz dans le réseau de gaz naturel. 94701 Maisons-Alfort, French Agency of Occupational and Environmental Health.

AFSSET. 2007. Valeurs guides de qualité d'air intérieur. Le formaldéhyde. 94701 Maisons-Alfort, French Agency of Occupational and Environmental Health.

National Research Council. 1983. Assessment in the Federal Government: Managing the Process. Washington, DC, National Academy Press.