
# **Le utenze domestiche alimentate con idrogeno:** studio delle problematiche di sicurezza

Ing. Stefano Marsella - Dipartimento dei Vigili del fuoco, del soccorso pubblico e della difesa civile

Roma - 10 dicembre 2021

## l’uso domestico di idrogeno

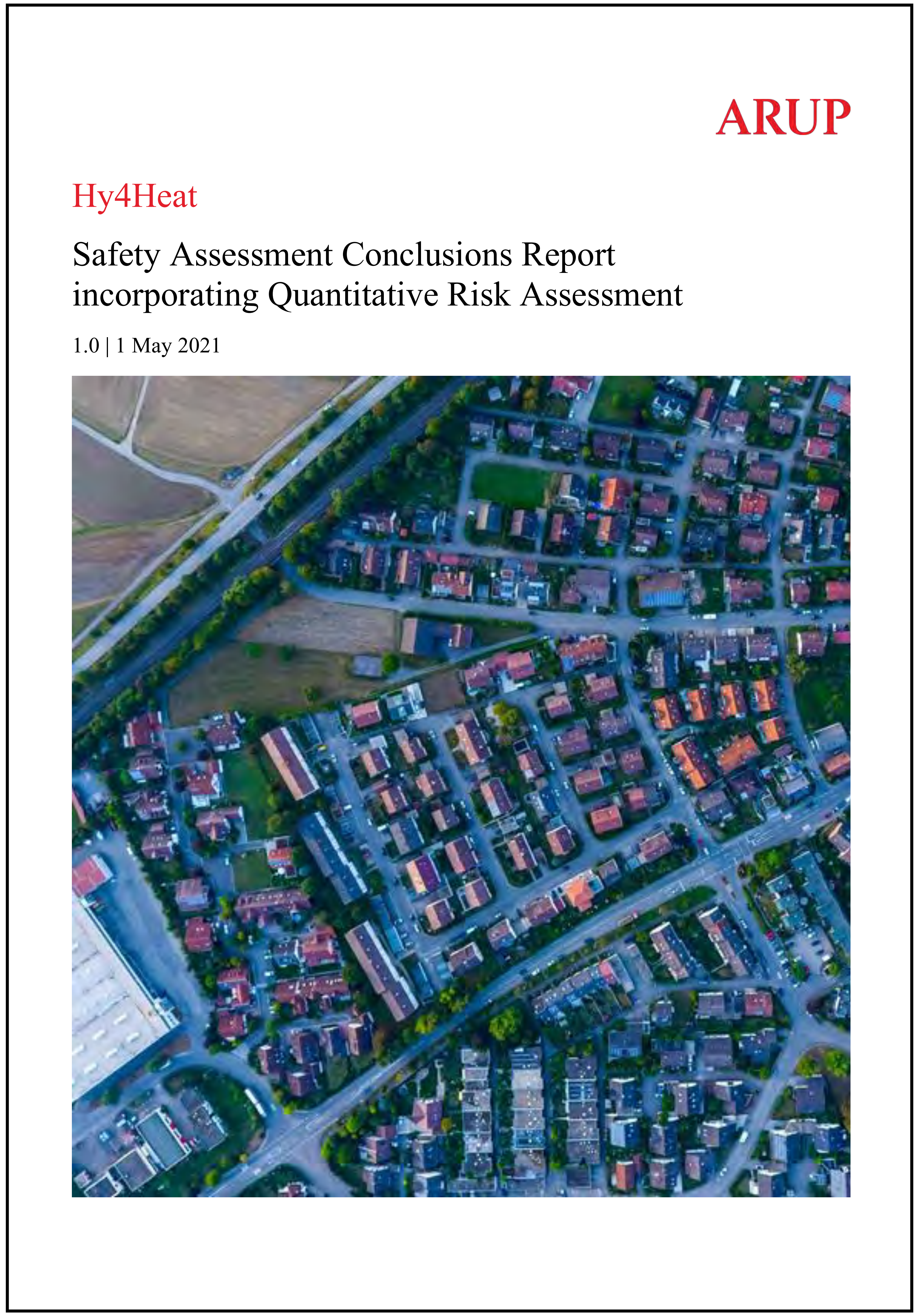
- perché è necessario approfondire questo tema

- illustrazione dell’analisi quantitativa dei rischi prodotta da ARUP per il Governo UK (maggio 2021)

- considerazioni finali

parole chiave: **Hydrogen, Residential, Risk -** prime dieci pagine google - la lista non è esaustiva


- George V. Alexeeff, David C. Lewis, Nancy L. Ragle Estimation of Potential Health Effects from Acute Exposure to Hydrogen Fluoride Using a “Benchmark Dose” Approach Risk Analysis, 1993
- **Ahn, Jae-Uk, et al. "A CFD Study on the Hydrogen Leakage for Residential Fuel cell System."** ***Proceedings of the KSME Conference*****. The Korean Society of Mechanical Engineers, 2007.**
- Barbara S. Zaunbrecher, Thomas Bexten, Manfred Wirsum, Martina Ziefle, What is Stored, Why, and How? Mental Models, Knowledge, and Public Acceptance of Hydrogen Storage, Energy Procedia, 2016
- **M.R. Swain, M.N. Swain, Passive ventilation systems for the safe use of hydrogen, International Journal of Hydrogen Energy, 1996**
- **Ma Qingchun, Zhang Laibin, CFD simulation study on gas dispersion for risk assessment: A case study of sour gas well blowout, Safety Science, 2016**
- C.P. Medeiros, M.H. Alencar, A.T. de Almeida, Hydrogen pipelines: Enhancing information visualization and statistical tests for global sensitivity analysis when evaluating multidimensional risks to support decision-making, International Journal of Hydrogen Energy, 2016
- Badr H. Alharbi, Mohammad J. Pasha, Mohammed Ahmad S. Al-Shamsi, Firefighter exposures to organic and inorganic gas emissions in emergency residential and industrial fires, Science of The Total Environment, 2021
- **William M. Pitts, Jiann C. Yang, Matthew Blais, Alexandra Joyce, Dispersion and burning behavior of hydrogen released in a full-scale residential garage in the presence and absence of conventional automobiles, International Journal of Hydrogen Energy, 2012**
- **C.D. Barley, K. Gawlik, Buoyancy-driven ventilation of hydrogen from buildings: Laboratory test and model validation, International Journal of Hydrogen Energy, Volume 34, Issue 13, 2009**
- **Yassine Hajji, Mourad Bouteraa, Afif ELCafsi, Ali Belghith, Philippe Bournot, Ftouh Kallel, Natural ventilation of hydrogen during a leak in a residential garage, Renewable and Sustainable Energy Reviews, 2015**
- **Aanchal Shah, Vijay Mohan, John W. Sheffield, Kevin B. Martin, Solar powered residential hydrogen fueling station, International Journal of Hydrogen Energy, 2011,**
- **Yassine Hajji, Belgacem Jouini, Mourad Bouteraa, Afif Elcafsi, Ali Belghith, Philippe Bournot, Numerical study of hydrogen release accidents in a residential garage, International Journal of Hydrogen Energy, 2015,**
- **Youngdoo Kim, Jin Hyun Nam, Donghoon Shin, Tae-Yong Chung, Young-Gyu Kim, Computational fluid dynamics simulations for hydrogen dispersion and exhaust in residential fuel cell systems, Current Applied Physics, 2010**
- Daniela Nuvolone, Davide Petri, Pasquale Pepe, Fabio Voller, Health effects associated with chronic exposure to low-level hydrogen sulfide from geothermoelectric power plants. A residential cohort study in the geothermal area of Mt. Amiata in Tuscany, Science of The Total Environment, 2019
- Sharifah Mazrah Sayed Mohamed Zain, Rafiza Shaharudin, Muhammad Amir Kamaluddin, Siti Fatimah Daud, Determination of hydrogen cyanide in residential ambient air using SPME coupled with GC–MS, Atmospheric Pollution Research,2017
- **B. Boukhris, Moahmed Mediouni, L. Elmahni The Study of the Prefeasibility of a Hydrogen Hybrid PV System in an Isolated Residential Site in Southern Morocco Applied Journal of Environmental Engineering Science, 2018**
- **Daniel R. Jones, a Waheed A. Al-Masryb and Charles W. Dunnill  Hydrogen-enriched natural gas as a domestic fuel: an analysis based on flash-back and blow-off limits for domestic natural gas appliances within the UK Sustainable Energy Fuels, 2018,**
- **Julien Mouli-Castillo a,*, Stuart R. Haszeldine a, Kevin Kinsella b, Mark Wheeldon c, Angus McIntosh c A quantitative risk assessment of a domestic property connected to a hydrogen distribution network international journal of hydrogen energy 46 2021**
- **Livio de Santoli, Romano Paiolo, Gianluigi Lo Basso,  An overview of safety issues related to methane blend applications in domestic and industrial use  Energy Procedia  2017**
- **Alina E. Kozhukhova  , Stephanus P. du Preez  and Dmitri G. Bessarabov  Catalytic Hydrogen Combustion for Domestic and Safety Applications: A Critical Review of Catalyst Materials and Technologies Energies 2021,**
- **South Australian Government Department of Energy and Mining  GPA Engineering Pty Ltd Hydrogen Impacts on Downstream Installations and Appliances 2019**


ARUP

Hy4Heat

Safety Assessment Conclusions Report
incorporating Quantitative Risk Assessment

1.0 | 1 May 2021

**The aim of the Hy4Heat programme is to establish if it is technically possible**, safe and convenient to replace natural gas with hydrogen in residential and commercial buildings. This will enable the government to determine whether to proceed to community trials.

The safety assessment covers leaks occurring downstream of the emergency control valve (ECV). The assessment **is valid for masonry-built terraced, semi-detached, or detached properties**. This includes homes and 'light' commercial premises such as corner-shops. This covers the majority of domestic settings and is believed to be sufficient for a broad range of potential community trials. Note that **blocks of flats, houses in multiple occupation, those with mechanical (forced) ventilation, prefabricated and high-rise buildings are excluded from the assessment** and so should not be considered as subjects for hydrogen trials, until further work is undertaken.

In order to compare the safety risks associated with each gas (i.e. natural gas and hydrogen gas), a QRA (quantitative risk assessment) was conducted to obtain **numerical estimates of the safety risks for each gas from a quantitative consideration** of the event probabilities and consequences. The numerical results from each of the QRA for both gases were then compared and evaluated (taking into account any proposed safety mitigation measures) against the risk acceptance criteria.

definizione requisiti edificio di test

dati delle sperimentazioni

raccomandazioni di sicurezza

**definizione degli scenari per test** → **realizzazione di un edificio per test** → **definizione dell'analisi quantitativa dei rischi** → **test su edifici reali**

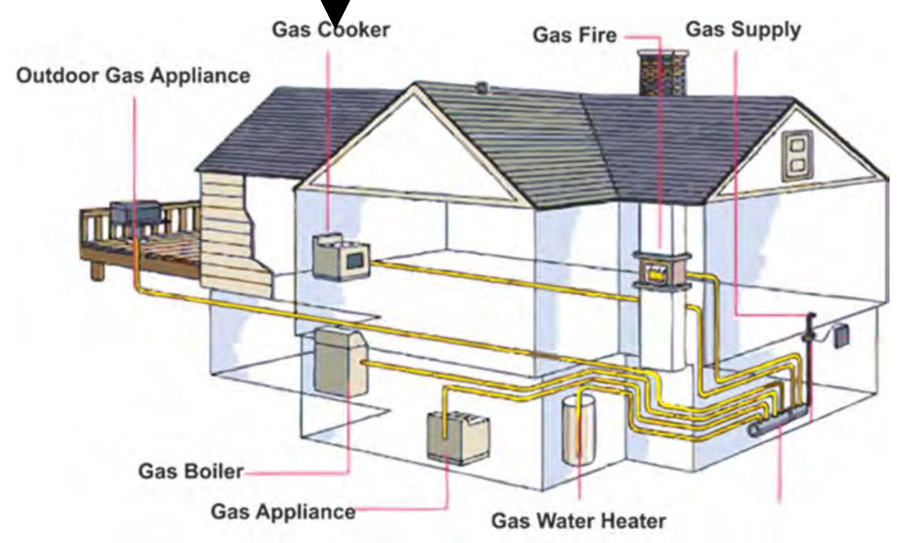



*Figure 2: Example of domestic gas pipework*

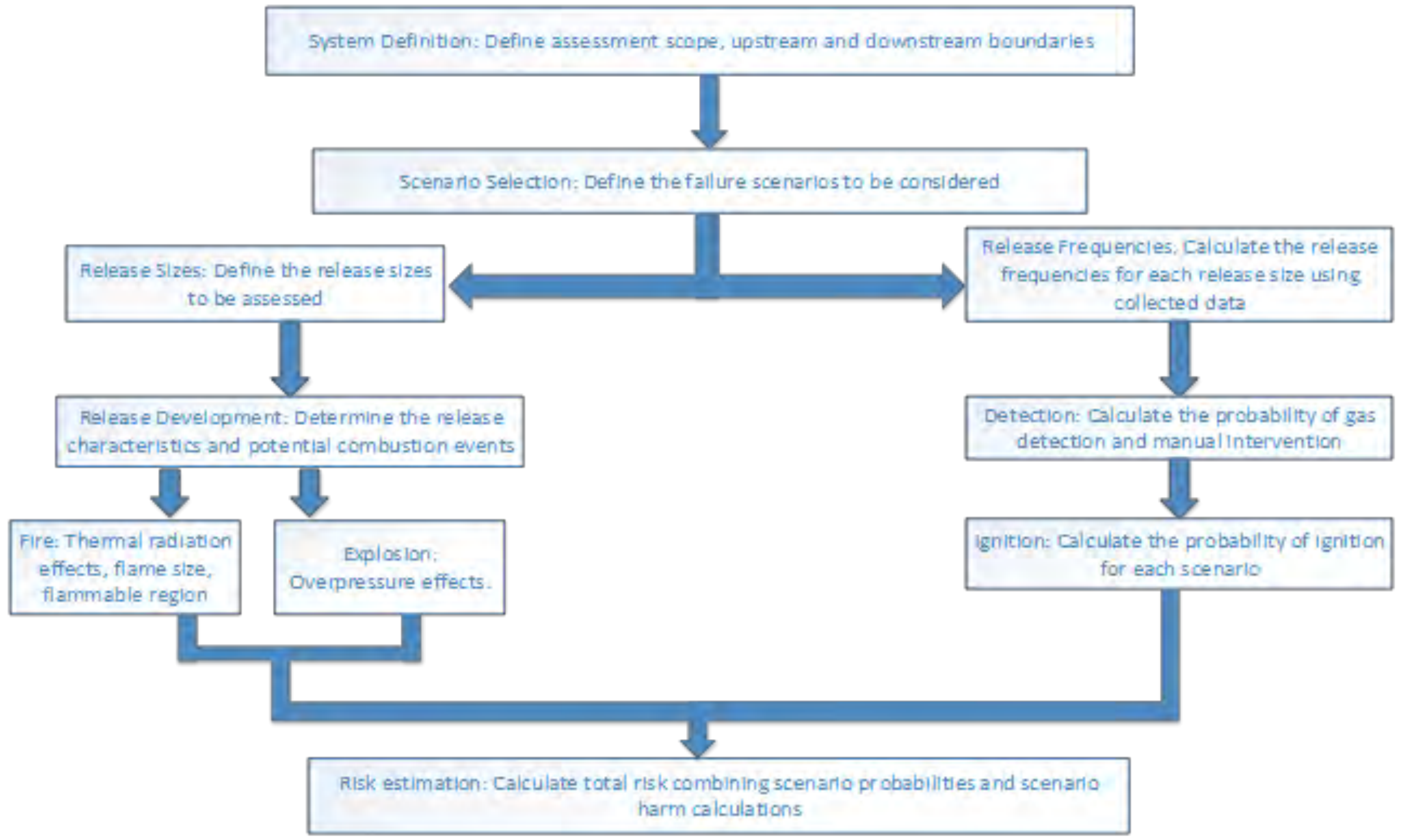




Figure 5: QRA methodology

$H_2 \neq CH_4$

# The key differences in risk between hydrogen and natural gas (methane)

are associated with their inherent properties and behaviour, these include:

- **Hydrogen will leak approximately three times the volume through a given hole** size under a given pressure compared with methane.

- **The energy density of hydrogen is approximately one third lower** than that of methane

- **The density of hydrogen is approximately one-eighth** that of methane. As a result, hydrogen is more buoyant, leading to larger convective forces, and consequently hydrogen dispersing more quickly than methane.

- **The flammability range of hydrogen (about 4 to 74%)** is greater than methane (5-15%)

- **Hydrogen has a lower minimum ignition energy,** particularly in the concentration range 10 – 50 %vol.

- **Hydrogen and methane differ in their stoichiometric concentration** (approximately the concentration at which there is the optimum mix of gas and air for ignition): (hydrogen: ~28.9 %vol, methane: ~ 9.5 %vol). The gases differ therefore in the relationship between average gas concentration in the flammable mixture and the explosion overpressures resulting from the explosion, based on how close the average gas concentration is to being stoichiometric (but also see note relating to laminar burning velocity below).

- **In hydrogen compared to methane explosions,** the consequences of the explosion have the potential to be worse in the case of hydrogen. This is because the laminar burning velocity of hydrogen is approximately eight times higher than that of methane.

- **Both hydrogen and natural gas (methane) deflagrate** (burn) in a broadly similar fashion (in a domestic and commercial situation).

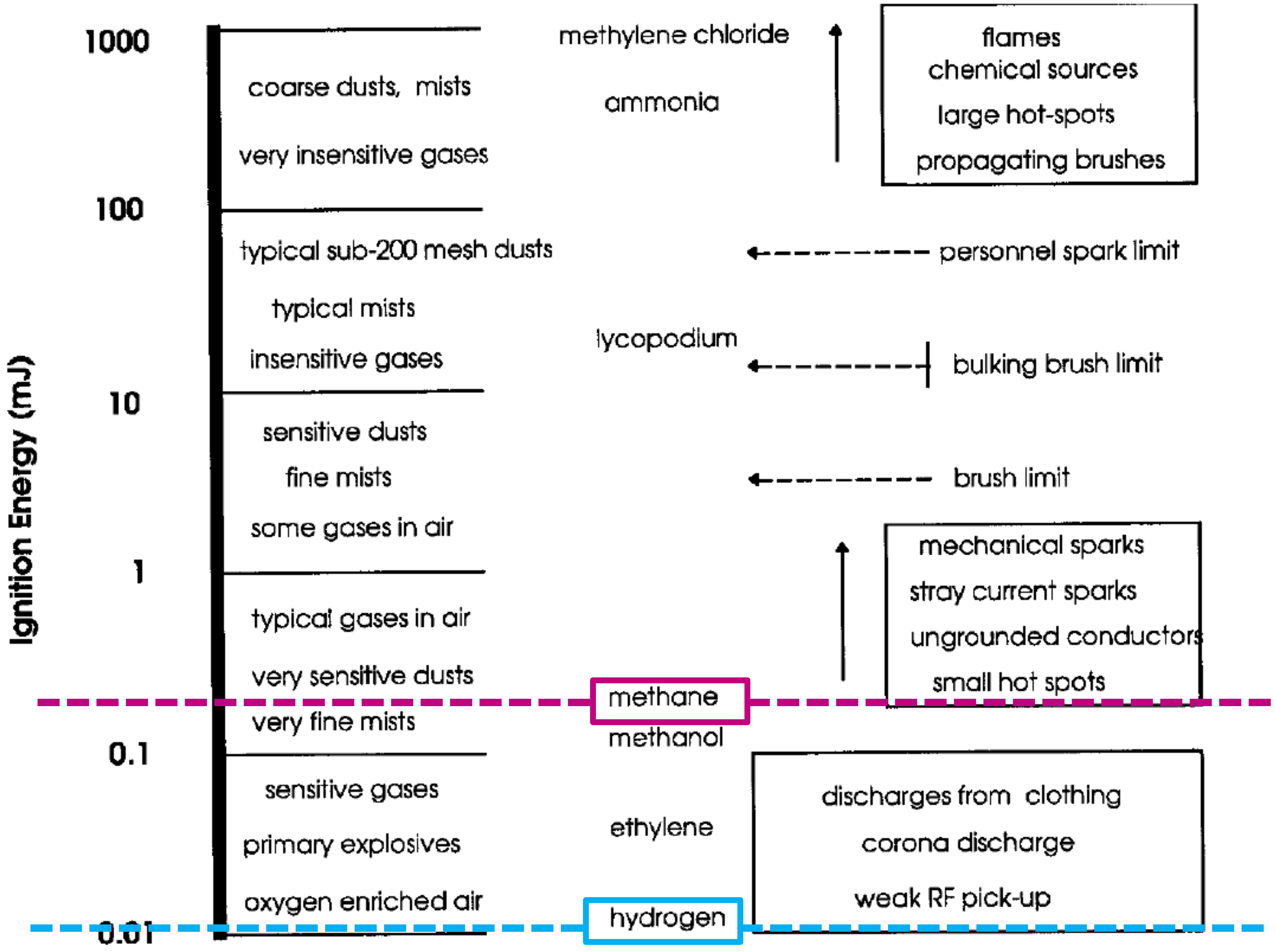



Figure 6. Ignition energies (mJ) of various materials and types of ignition source that may ignite them [7, figure 2.5]

**A number of assumptions are made** in the safety assessment. The key assumptions, and the principal reasons why the assumption has been made in the way it has, are as follows:

- **The internal pipework and fittings for hydrogen gas are the same as for natural gas**. There is no evidence to suggest that pipework requirements will need to be amended for the conveyance of hydrogen. The assessment also assumes that the pipework and fittings fully comply with any regulatory requirements.

- **The causes of an initiating leak event (e.g. pipework damage, third party interference) will be unchanged** from natural gas to hydrogen gas. This is because these are, broadly, independent of the gas being conveyed.

- **Consumer behaviour is assumed to remain unchanged** from natural gas to hydrogen gas, including their response to a suspected leak, because the same odorant will be used for hydrogen gas. This will ensure that the familiar smell people are used to responding to is unchanged.

- **No centrally added colourant is added in the distribution network**. This is because the technical and logistical issues with introducing a colourant into a network are significant and not fully understood and may introduce additional risk without significant benefit.

- **Appliances are all safety certified in accordance relevant legislation**

- **Competent installers will all be Gas Safe certified for hydrogen.** This will ensure any hydrogen system is installed to the same standard of safety as current natural gas standards require.

- **Principles from the IGEM Hydrogen Reference Standard** are to be applied during any potential community trial, because these standards outline the key differences associated with hydrogen gas compared to natural gas and how to manage these safely.

- **All gas service pipes supplying properties are installed to current natural gas standards** to ensure they are in line with the current recommended standard of safety.

# i risultati

# Risk reduction measures

## The following risk reduction measures are recommended to be put in place for a community trial:

**The following regulations and standards shall be complied with:**

- Gas Safety (Installation & Use) Regulations
- IGEM Hydrogen Reference Standard (IGEM/H/1) or equivalent hydrogen specific amendments to existing IGEM natural gas standards
- As and when it is completed, the BSI PAS Installation Standard – pipework and ventilation, and other relevant IGEM standards
- All hydrogen appliances must be new (domestic or commercial), certified by a Notified Body in accordance with Gas Appliances (Enforcement), Miscellaneous Amendments Regulations with the use of PAS 4444 including FFDs fitted on all appliances
- Installed hydrogen smart gas meters must be new, certified by a Notified Body (for metrology and safety), and be SMETS2 compliant

**EFV to limit the flow rate to 20m$^3$/hr in the service pipe.** This is either to be installed as a retrofit or as part of new installation. The installation of this mechanical excess flow valve should conform to the functionality of the standard ASTM F2138 - 12(2017) (Standard Specification for Excess Flow Valves for Natural Gas Service) or similar publicly acknowledged industry standard. It shall be located in either of the following locations: In the service pipe itself , Immediately after the ECV

**Hydrogen gas meter** containing an integrated EFV to limit the flow rate to <20m$^3$/hr or set at a lower value that is related and proportionate to the maximum usage of appliances installed within the individual property. Minimum values for the setting of this should be agreed with appliance manufacturers.

**Meter connections** shall comply with the "Specification for gas meter unions and adaptors" upgraded from the Natural Gas specification (BS 746:2014) for use with hydrogen.

**Hydrogen gas meter location:** Hydrogen gas meters should be installed outside of the property* and comply with current best practice and BS6400-1:2016. **where it is inappropriate to install the meter outside the property, then the GDNO shall conduct a full risk assessment for the individual property and ensure that any installation is within two metres of the service pipe entry*

**Ventilation …**

**Internal pipework (downstream of the ECV) …**

# 9 Results – base case

Table 29: Natural gas base case risk results

| Type of event | Predicted number of events per year (GB population) | Predicted number of individuals injured per event | Predicted number of individuals injured (per year GB) |
|---|---|---|---|
| Kitchen explosion (5-7.5 vol%) | 3.5 | 0.35 | 1.2 |
| Kitchen explosion (7.5-14 vol%) | 2.2 | 2 | 4.4 |
| Kitchen explosion (14-15 vol%)[3] | 0 | 0.35 | 0 |
| Whole downstairs explosion (5-6.5 vol%, or 11-15 vol%) | 1.5 | 0.9 | 1.4 |
| Whole downstairs explosion (7-11 vol%) | 1.8 | 5.5 | 10.1 |
| **Total** | [illegible] | **n/a** | **17** |

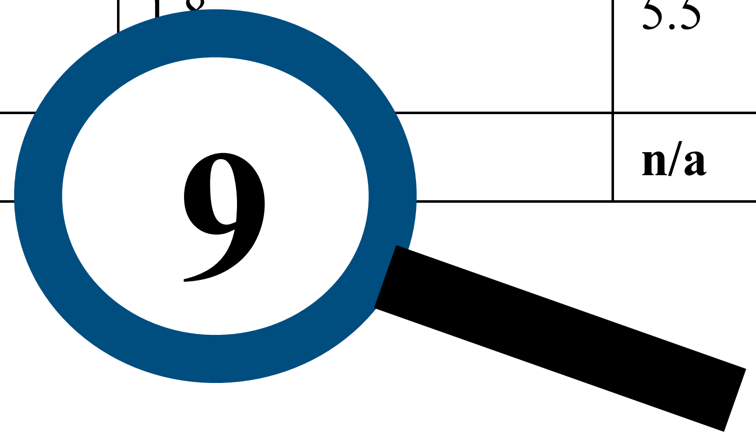
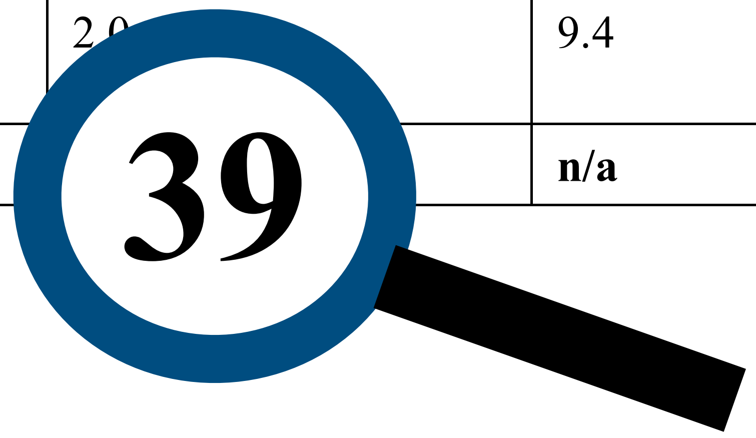



Table 30: Hydrogen gas base case risk results

| Type of event | Predicted number of events per year (GB population) | Predicted number of individuals injured per event | Predicted number of individuals injured (per year GB) |
|---|---|---|---|
| Kitchen explosion (5-14 vol%) | 20.0 | 0.35 | 7.0 |
| Kitchen explosion (14-23 vol%) | 2.8 | 2.3 | 6.5 |
| Kitchen explosion (>23 vol%) | 2.8 | 7.4 | 20.4 |
| Whole downstairs explosion (5-13 vol%) | 11.4 | 0.9 | 10.2 |
| Whole downstairs explosion (13-21 vol%) | 0.4 | 5.5 | 2.4 |
| Whole downstairs explosion (>21 vol%) | 2.0 | 9.4 | 18.8 |
| **Total** | [illegible] | **n/a** | **65** |




decessi anno

# 10 Results – with additional risk reduction measures

Table 29: Natural gas base case risk results

| Type of event | Predicted number of events per year (GB population) | Predicted number of individuals injured per event | Predicted number of individuals injured (per year GB) |
|---|---|---|---|
| Kitchen explosion (5-7.5 vol%) | 3.5 | 0.35 | 1.2 |
| Kitchen explosion (7.5-14 vol%) | 2.2 | 2 | 4.4 |
| Kitchen explosion (14-15 vol%)[3] | 0 | 0.35 | 0 |
| Whole downstairs explosion (5-6.5 vol%, or 11-15 vol%) | 1.5 | 0.9 | 1.4 |
| Whole downstairs explosion (7-11 vol%) | [illegible] | 5.5 | 10.1 |
| **Total** | [illegible] | **n/a** | **17** |

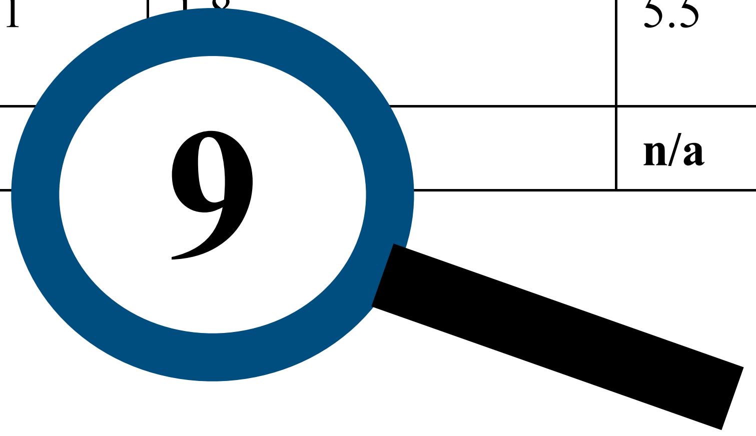
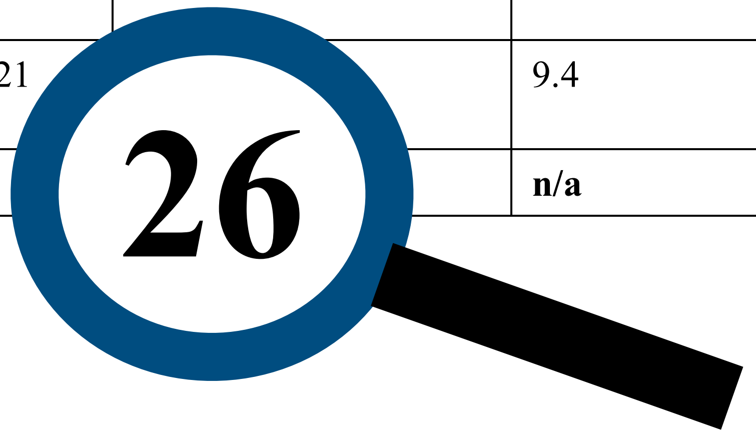



Table 31: Hydrogen (+EFVs) gas risk results

| Type of event | Predicted number of events per year (GB population) | Predicted number of individuals injured per event | Predicted number of individuals injured (per year GB) |
|---|---|---|---|
| Kitchen explosion (5-14 vol%) | 18.5 | 0.35 | 6.5 |
| Kitchen explosion (14-23 vol%) | 0.4 | 2.3 | 1.0 |
| Kitchen explosion (>23 vol%) | 0.05 | 7.4 | 0.3 |
| Whole downstairs explosion (5-13 vol%) | 6.5 | 0.9 | 5.8 |
| Whole downstairs explosion (13-21 vol%) | 0.4 | 5.5 | 2.4 |
| Whole downstairs explosion (>21 vol%) | [illegible] | 9.4 | 0.3 |
| **Total** | [illegible] | **n/a** | **16** |




decessi anno con misure di adeguamento

e Telegraph News Business Sport Opinion Politics World Money Life Style Travel Cultur Subscribe now Free for one month Log in

UK news Coronavirus Royals Health Defence Science Education Environment Investigations Global Health Security

# Hydrogen boilers could cause four times as many explosions as gas

Safety fears as government-backed assessment finds the alternative fuel could spark as many as 39 blasts a year

*By* Emma Gatten, ENVIRONMENT EDITOR

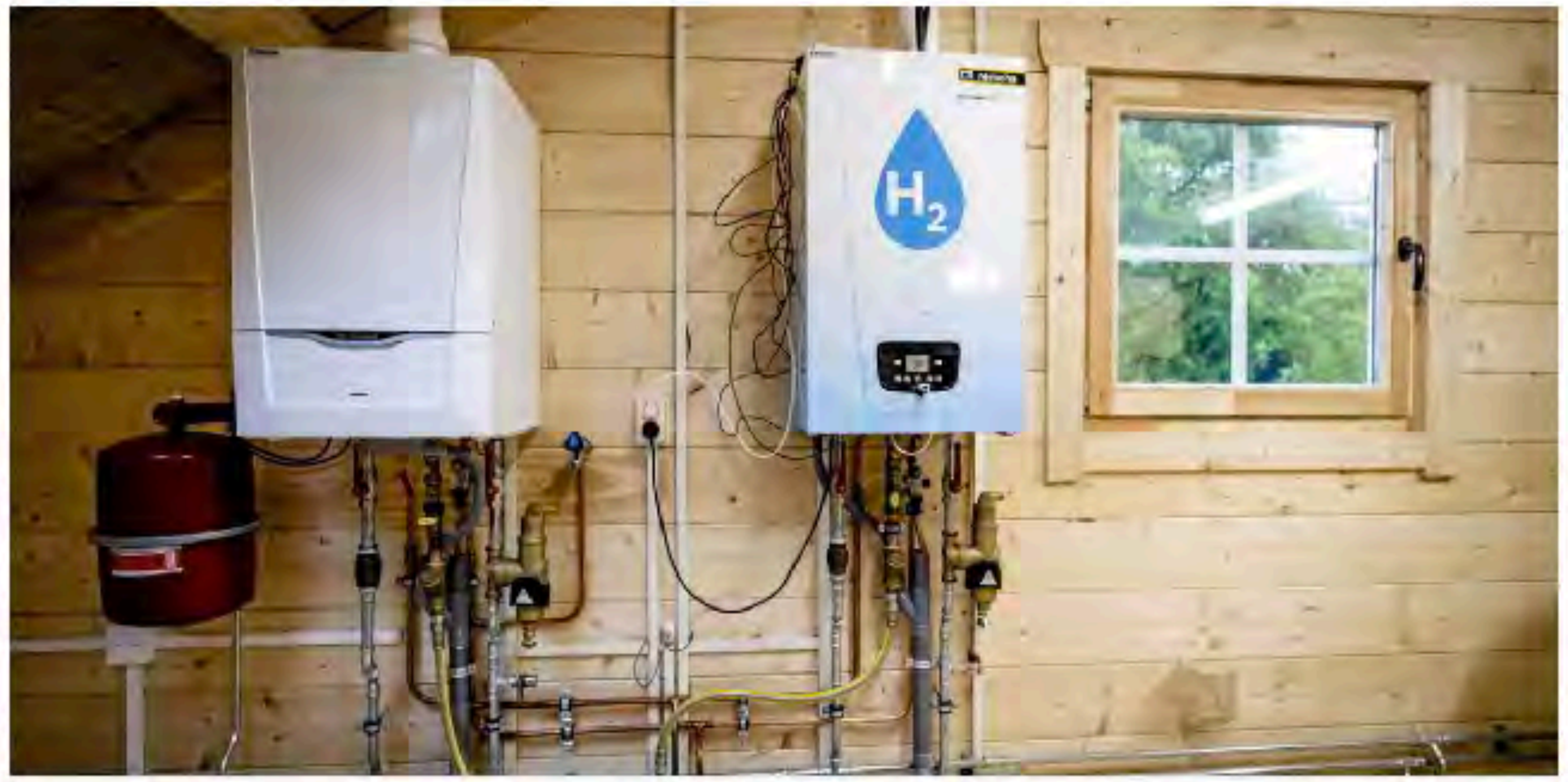
4 August 2021 • 6:42pm

RECHARGE Global news and intelligence for the Energy Transition News Analysis In-Depth Interviews Opinion Editions Electric City

ENERGY TRANSITION

See all articles

Alert me about Energy Transition




# 'Hydrogen in the home would be four times more dangerous than natural gas': government report

The predicted number of domestic gas explosions and resulting injuries would rise fourfold if H2 replaced methane, according to a safety assessment produced for the UK's energy ministry

Table 28: Summary of HSE GSMR incident data (data for incidents originating downstream of the ECV)

| Year | Fires and/or explosion incidents | Incidents with injuries |
|---|---|---|
| 2016/17 | 18 | 9 |
| 2017/18 | 13 | 8 |
| 2018/19 | 6 | 5 |
| 2019/20 | 9 | 5 |

Table 32: Comparison of predicted number of injuries for the natural gas base case, hydrogen base case, and the hydrogen gas case with two EFVs installed*

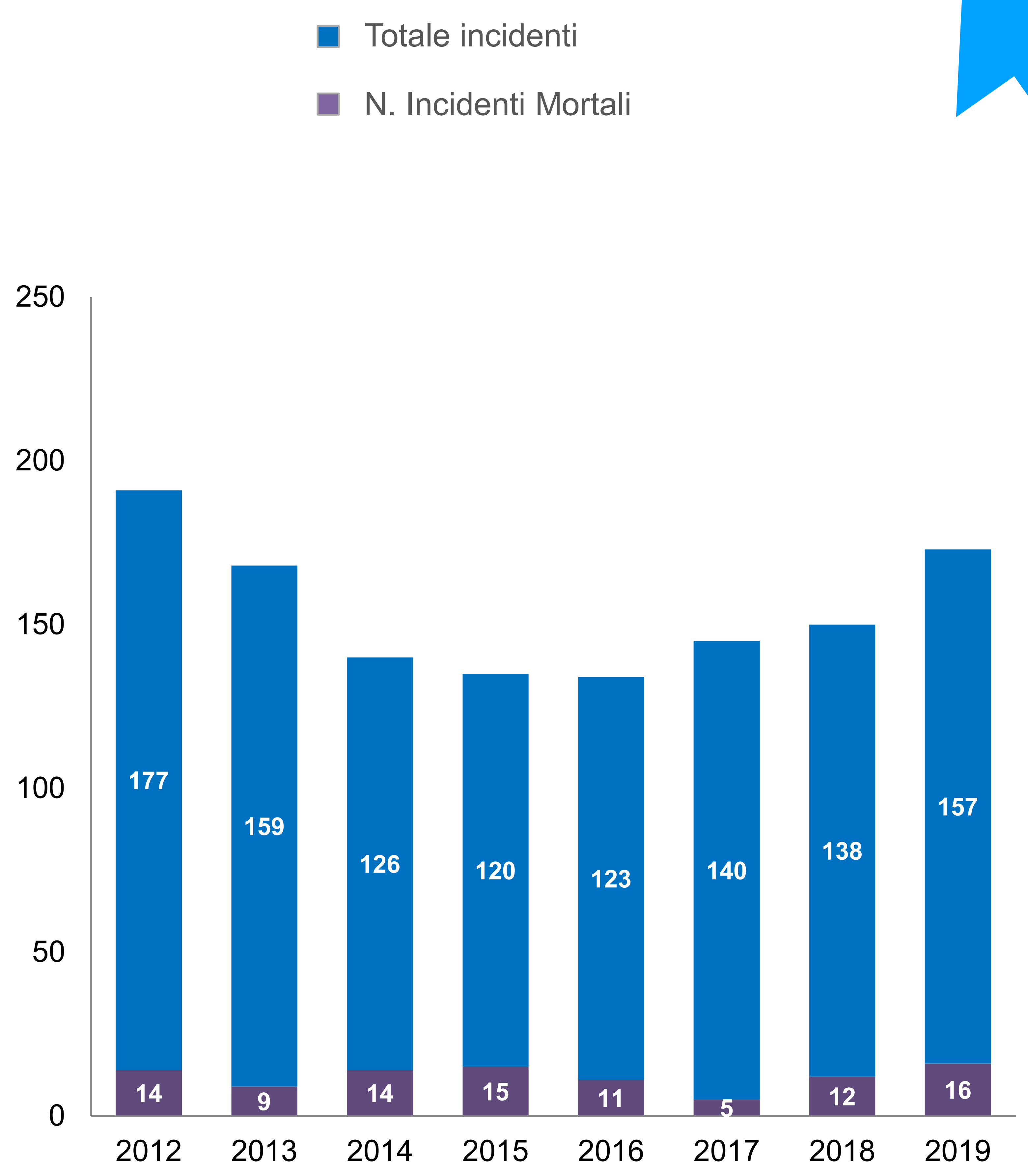
| | Indicative average annual number of injuries (HSE GSMR Data 2016-2020*) | Natural gas – Predicted number of individuals injured (per year GB) | Hydrogen base case – predicted number of individuals injured (per year GB) | Hydrogen + 2EFVs – predicted number of individuals injured (per year GB) |
|---|---|---|---|---|
| **Total estimated no. of injuries per year**:** | **12*** | **17** | **65** | **16** |

*Note: These numbers should be considered in orders of magnitude rather than absolute values*

**i dati non sono comparabili, ma…**

**DATI REGNO UNITO INCIDENTI GAS NATURALE**

**DATI REGNO UNITO - PREVISIONE RICERCA ARUP**




**DATI CIG - 2019 INCIDENTI GAS CANALIZZATO**

## conclusioni

lo studio del governo UK appare solido ma non può essere utilizzato in Italia a causa della diversità di scenari, di limitazioni e di assunzioni

↓

per introdurre l'uso domestico dell'idrogeno è necessaria una ricerca specifica grazie per l’attenzione