November 2010

Position Paper: Natural Gas – Hydrogen Blends Technology

A position paper of NGVA Europe, prepared by:
G. Miletto, E. Volpi – Metatron;
M. Ferrera, A. Gerini – Fiat Powertrain Tecnologies;
A. Fuganti – Centro Ricerche Fiat.

Introduction

Today, natural gas and biomethane represent the most practical, realistic and easiest way to reduce pollution coming from road transportation. At the same time, Hydrogen as a vehicle fuel certainly is an interesting solution taking into account its environmental benefits. However, and to be realistic, fully propelled hydrogen vehicles still remain an insecure long term option facing various obstacles, which must be solved first: open questions include e.g. production pathways with regard to coherent pollution, energy and cost dimensions; the organization and realization of a dedicated distribution network; the complexity and cost of hydrogen vehicles and their main components, etc.

As a natural consequence, the intention of this paper is to present the huge potential that methane/hydrogen blends can bring for the transport sector, as an ideal bridge to a more sustainable mobility, by using the existing NG/biomethane distribution infrastructure.

Production related aspects

A certain quantity of hydrogen is already available today, at least in some places.

Just to give you an example (see Figure 1) we can report the situation in Italy where there are many locations where hydrogen is industrially produced, mainly by steam reformer on natural gas or higher hydrocarbons.

SPEAKING ABOUT HYDROGEN…..

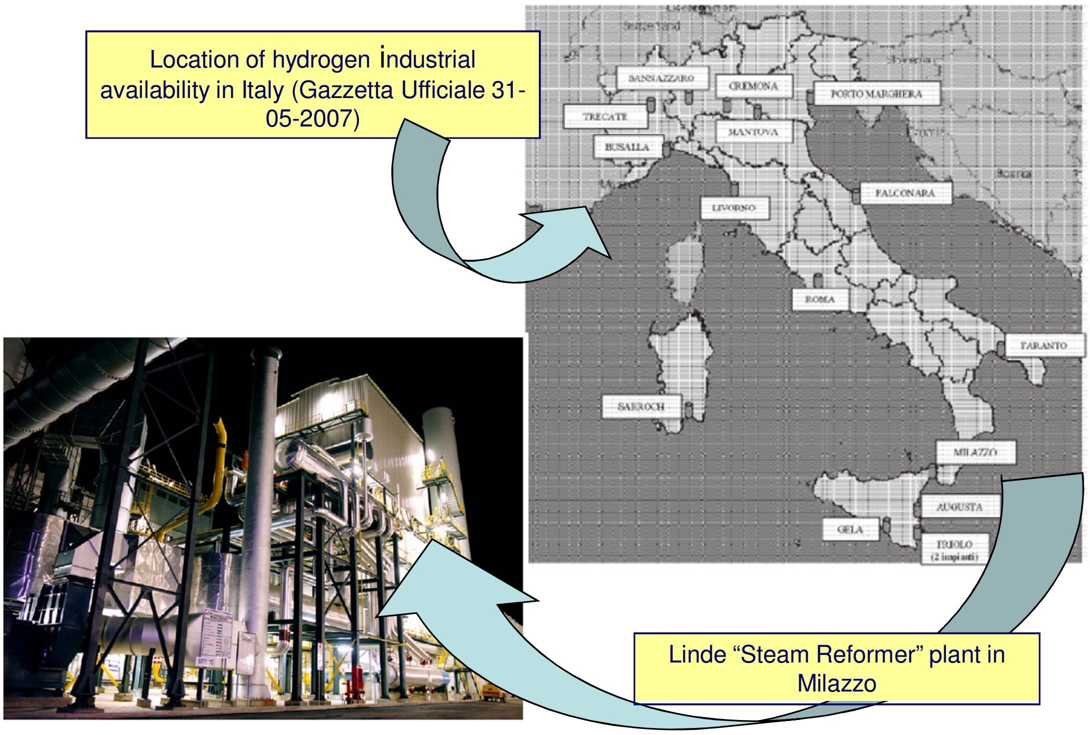


Figure 1

Another source of hydrogen, perhaps more important at least in Italy, is based on hydroelectric energy: it is well known that the production of hydrogen is a good storage system when energy consumption is very low (i.e. during the nighttime); this approach is also under development in the area of Trentino Alto Adige, which is already equipped with several hydroelectric power plants. Moreover other technologies are under investigation for production of green hydrogen from renewable energies such as photovoltaic, wind and biomass.

Several application programs are in progress; one of the main interesting ones will be carried out along the interstate A22 Motorway with the main following objectives:

- To test the production of green hydrogen from renewable sources according to various technologies (hydroelectric, photovoltaic, wind, biomass).
- The availability of new generations of multi-fuel filling stations every 100 km supplying Natural Gas, Hydrogen/NG blends and Hydrogen between Modena and Munich.

- The creation of a "hydrogen" corridor having a length of 600 km and a width of 300 km, through hydrogen connection with multi-fuel filling station along side the motorway.

So, even if for the moment, the production of hydrogen is clearly limited to industrial applications and not finalized to transportation fuel, some quantity of hydrogen may, or should be, however available.

It is now clear that, even if we confirm today once again the realistic actuality of natural gas, the future potential of hydrogen cannot be disregarded, and both "clean" fuels, natural gas and hydrogen must be considered.

Technology related aspects

Taking into account these considerations any vehicle using a powertrain is basically able:

- to run with natural gas/biomethane (doesn't matter if it is one or the other because both of them have the same chemical composition)
- to include also hydrogen, if and where it is available, to be used as blended fuel
- to automatically adapt its engine control system to the characteristics of "in use" fuel
- to maintain a cost similar to present gas engines

All these requirements may be reasonably satisfied by a new fuel: the natural gas – hydrogen blends.

We have to underline that perhaps the most important feature of this approach is that it does not require a revolution of the engine technology but only an evolution of the already existing natural gas engine.

The advanced technology of hydrogen/natural gas blends can offer an important contribution vs. the emissions reduction and guarantee a strong positive synergy with gaseous fuels from renewable sources such as biomethane and green hydrogen.

Moreover, the addition of hydrogen to natural gas improves the environmental properties of natural gas when burning in internal combustion engines.

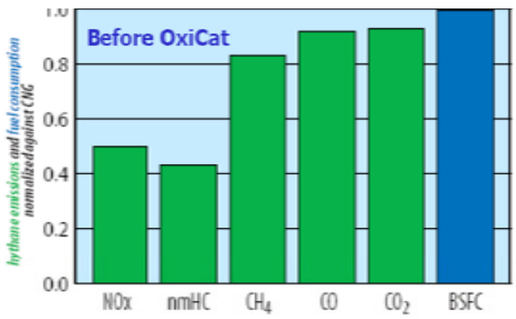
From another point of view we can say that mixtures of natural gas and hydrogen can in some way speed up the development of the hydrogen infrastructure considered necessary for future transport options.

The story of natural gas-hydrogen blends (see Figure 2) begins more or less twenty years ago with the invention of "hythane", a blend of 20 % of hydrogen and 80% of natural gas in volume, patented to reduce the raw NOx emissions of passenger cars as a consequence of the lean limit potential extension, a concept well known to engine engineers.

THE STORY BEGINS……

…. with the birth of Hythane® , blend of 20% hydrogen and 80% natural gas by volume, invented in 1989 by F. Lynch – R. Marmaro and patented in 1992 as a fuel to reduce the NOx emissions (lean limit extension)

Published emission reduction



® Hythane is a trademark of property of Eden Innovations *Ltd* (originally called Brehon Energy PLC), a wholly owned subsidiary of *Eden* Energy *Ltd,* but today is very often used to nominate every methane hydrogen blends [8]

Figure 2

Probably it is not so much well known that the testing of hythane was also carried out in the field of heavy duty applications for many years and in different countries.

To quote only some of these experiences (see Figure 3) there have been tests carried out in USA in the last decade of the past century and later on, there were experiments in Sweden, China, France and India.

HYTHANE HISTORY IN HD APPLICATIONS

• **1992 – 1995** – Preliminary basic tests by G.M. Canada ,Toronto University, Colorado State University…..

• **1995** – **Canada** : Demonstration in Montreal by Novabus with Cummins/Westport engine.

•**2000/2001** – **California** : Bus demonstrator (Cummins/Westport engine) operated by SunLine Transit Agency

• **2002/2003** – **Sweden** :Hythane Malmö project : basic combustion studies by Lund Institute/Swedish Gas Company on 2 buses (Volvo engines)

• **2005** – **China** : Yuchai 7.9l engine adaptation

• **2006** - **France** : Althytude project : two cities (Dunkerque and Toulouse) with 2 Irisbus busses (FPT engines)

• **2006** – **India** : Ashok Leyland 6.0 l engine adaptation

9 Not exhaustive/complete list !

Figure 3

In Italy the main focus was addressed to passenger cars and delivery vans (see Figure 4), but urban transports were not forgotten.

…. AND IN ITALY?

MAIN FOCUS ON PASSENGER CARS/DELIVERY VANS :

- Performances analysis on FIAT Punto Natural Power (Second University of Naples)
- Bong-Hy project on IVECO Daily (ENEA)
- Regione Lombardia project on 20 Panda Natural Power “ad hoc” modified (Centro Rcerche Fiat, ENI, Sapio, NCT, FAST)

…..BUT SOME EXPERIENCE ALSO ON HEAVY DUTY VEHICLE

- Study for the use of hydrogen-natural gas on bus in urban context (ENEA with Regione Emilia Romagna)

Figure 4

In this context it is worth to point out that the more extensive testing plan is in progress in Lombardia, a region of Italy, where 20 modified FIAT Panda Natural Power cars (adapted for the use of a blend of Natural Gas with 30% of Hydrogen in volume) are in testing together with 2 blend refuelling stations (see Figure 5).

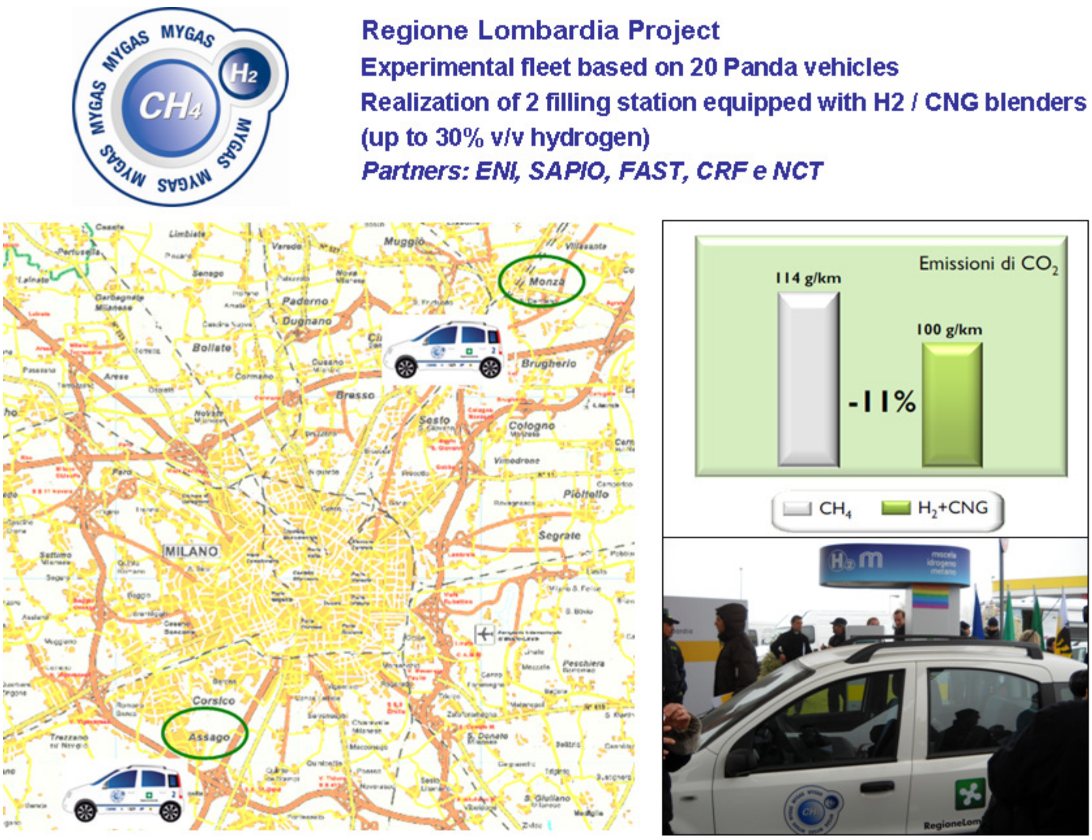


Figure 5

Some tests for heavy duty application in city context are also in progress in the Emilia Romagna region, besides the more famous experimental programme carried out by the Althytude Project in Dunkerque (France) with two Irisbus buses modified to run with a NG/hydrogen blend using 20% hydrogen by volume (see Figure 6).

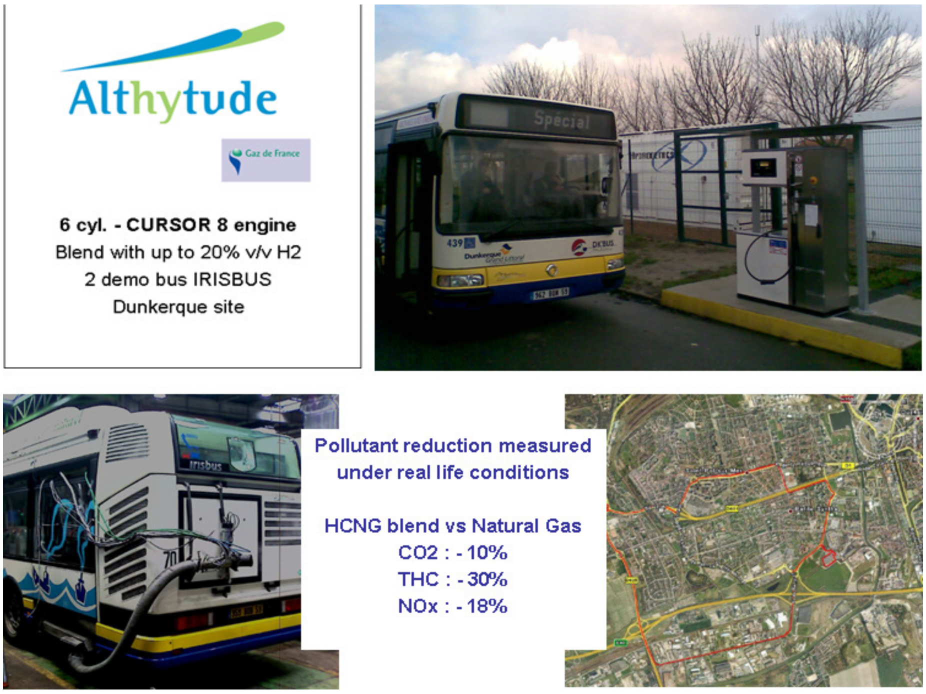


Figure 6

As we have seen, “hythane” is a trade mark for a specific composition (20% of hydrogen and 80%of natural gas).

To take into account different and more general compositions, it should be better to use a different name, for example hydromethane which may be shortened with HCNG.

Moving to the control system, the hardware does not require any modifications, while some adaptations to the software of engine control and to the calibration dataset are necessary. In this way it will be possible to take into account the physical properties of the fuel and to have the possibility of adapting the parameters of the engine control to different blend compositions, sweeping from pure natural gas to the maximum hydrogen content that the specific application can safely use. In fact, running the engine with the calibration dataset normally used for natural gas can induce an increase of pollutant emissions, due to the wrong air/fuel metering and to a non adapted control of the lambda probe closed loop (see Figure 7).

MINIMUM IMPACTS ON VEHICLE/POWERTRAIN TECHNOLOGY(2)

Engine control system & exhaust gas aftertreatment derived from CNG applications

But

➢Slightly modification to the SW of electronic engine control

➢Optimization of engine parameters calibrations

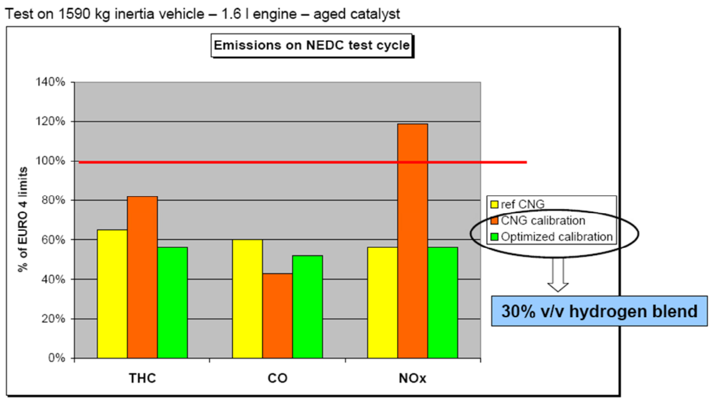


Figure 7

Of course this approach requires the availability of a gas engine equipped with an electronic gas injection system and an advanced engine control in order to exploit all the benefit from the hydrogen blend.

From the point of view of the compatibility of the materials, it is well known that the presence of hydrogen could cause some embrittlement phenomena with aging (see Figure 8). For these reasons, even if a smoothing effect is expected thanks to the partial pressure of hydrogen in the blend, an exhaustive overview of the problem based on laboratory and durability test is needed.

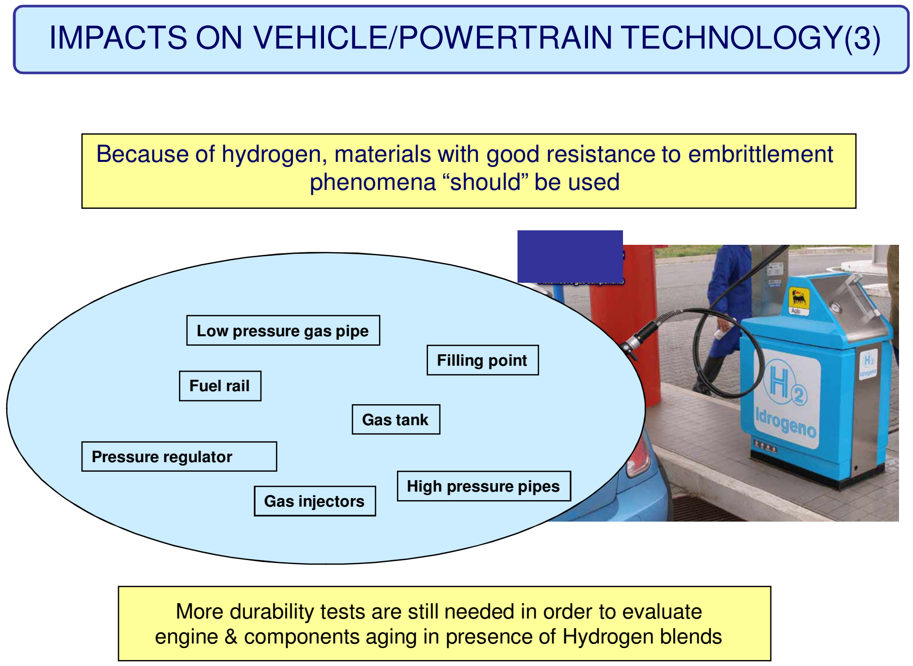


Figure 8

In the meantime it is recommended to use materials with good resistance to embrittlement phenomena, mainly the parts directly and permanently in contact with blend such as gas tank (to be noted that presently used CNG Type 1 steel cylinders are not approved to handle H_2 contents above 2%), pipes, fuel rail, and some details of pressure regulators and injectors.

Regarding the refueling process, it would be worth considering the use of a unique filling nozzle connection in order to ensure that vehicles with steel tanks do not refill HCNG.

But which are the reasons to use HCNG?

Benefits when using natural gas/hydrogen blends:

If we consider blends with hydrogen ranging from 10 to 30% it is possible to have, at the same time, significant environmental benefits together with minimum impact on vehicle and powertrain configuration.

In fact (see Figure 9) thanks to the hydrogen properties, in comparison with natural gas, the blend has higher H/C ratio, higher combustion velocity, and less ignition energy. This means that the combustion will result more complete, fast and stable.

HYDROGEN CHARACTERISTICS vs METHANE

With reference to methane hydrogen is characterized by :

❑ higher combustion velocity;

❑Less ignition energy;

which implies

➢ more complete combustion reactions;

➢ less engine cyclic variation;

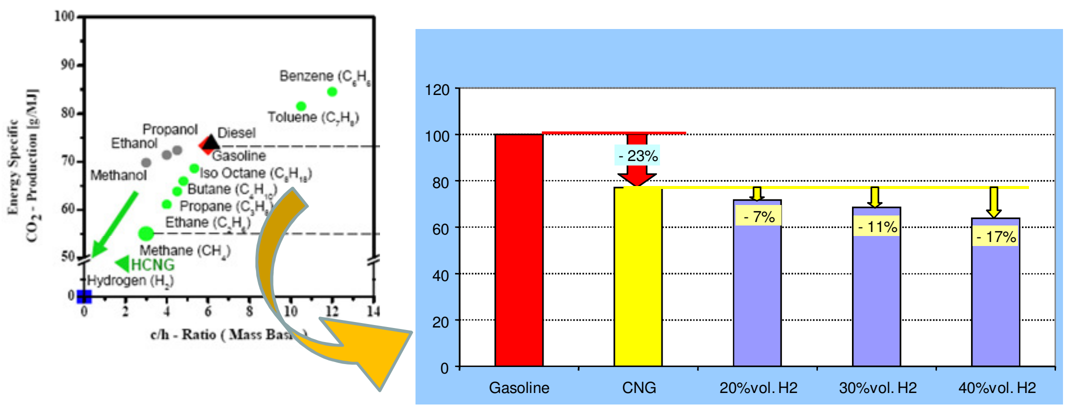
➢ increased speed of flame front in combustion chamber.

Figure 9

So, from the environmental point of view, the addition of hydrogen results in an increase of H/C ratio with a significant further reduction in CO_2 emissions in comparison with natural gas alone (see Figure 10). For example a blend with 30% of hydrogen will cause an additional 11% reduction in CO2 emissions in comparison to natural gas alone.

ENVIRONMENTAL BENEFITS

➢Additional reduction in CO_2 emissions



➢Reduction in THC and CO emissions(higher H/C ratio, reduction in flame quenching phenomena)

➢Potential increasing in engine efficiency (higher combustion speed)

Figure 10

Less evident but always interesting is the reduction of total unburned hydrocarbons and carbon monoxide emission due to the resulting higher H/C ratio and also to the reduction of flame quenching phenomena leading to a more complete combustion.

Moreover, thanks to a specific regulation of the lambda control parameters, also a reduction of NOx emissions can be achieved at the exhaust where the standard CNG dedicated catalyst formulation can be maintained.

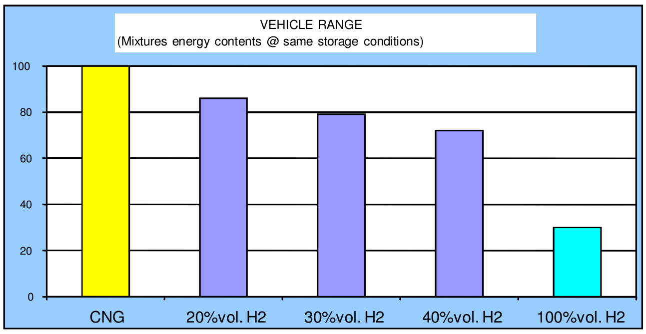
The increase of the flame propagation speed could also potentially result in slightly higher thermodynamic engine efficiency even if this aspect depends also on engine configuration and on its regulation.

But, apart from the environmental aspects, it is extremely important to notice that impacts of this fuel composition on vehicle and engine structure and technology are minimized.

Without changing the volume and the pressure conditions of the storage system it is possible to preserve a sufficient vehicle range: for instance, a 30% by volume hydrogen blend will reduce the energy content by approximately 20% compared to pure methane; this is an interesting result when we consider that, in the same conditions, pure hydrogen would reduce the vehicle range by more than 70% (see Figure 11).

MINIMUM IMPACTS ON VEHICLE/POWERTRAIN TECHNOLOGY(1)

- Acceptable reduction of the vehicle range compared to CNG and pure Hydrogen



- Engine control system & exhaust gas aftertreatment derived from CNG applications

- Limited upgrade of the CNG component materials for compatibility to Hydrogen

Figure 11

Also as far as regards safety no major problems are expected (see Figure 12). The only potential drawback is that, in case of leakage in the atmosphere, a demixing of the blend may occur. In this case, in closed room, we have to consider that the flammability range of hydrogen is much wider than that of natural gas.

SAFETY

Main properties of the base gases

	methane	hydrogen
Molecular weight	16,043	2,016
Fuel density (@ std cond)	0,717	0,089
Flammability limit in air - lower (% volume)	5	4
Flammability limit in air - upper (% volume)	15	74
Minimum autoignition temperature (℃)	580	570
Minimum ignition energy (mJ)	0,29	0,02
Laminar flame speed (m/s)	0,4	2,65
Diffusivity in air (dm3/s)	95	1636
Flame colour	blue	colourless

Which differences using HCNG mixtures compared to pure hydrogen ?

1) in case of leakage into atmosphere a demixing of the fuel occurs and the hydrogen fraction diffuses into air with its own properties: in closed room the flammability interval of pure hydrogen has to be considered;

2) a mixture leakage can be identified through the odour from the natural gas fraction (pure hydrogen is completely odourless);

3) the minimum value of the ignition energy is increased, thus allowing more safety to the mixture distribution operations; in case of leakage the same considerations as in item 1) have to be done;

4) the combustion flame is optically detected.

17

Figure 12

On the contrary some evident advantages, in comparison with pure hydrogen, are present: fuel leakage may be detected by natural gas odour, distribution operations may be more safety due to higher ignition energy, and combustion flame is optically detected while hydrogen combustion is not visible.

Conclusions

Finally we can draw the following general conclusions:

- mixing hydrogen in natural gas is profitable from the environmental point of view;
- in comparison with pure hydrogen, blends have no dramatic effects on vehicle range and engine performance;
- the best percentage of hydrogen depends on the engine configuration and mission, a 30% by volume hydrogen content may be considered a reasonable value;
- with hydrogen percentage less than 30% by volume no major problems are expected as far to regard to safety aspects and materials aging;
- HCNG may play an important role in the process of boosting future technology based on pure hydrogen;

At the end we may point out that, if today the use of mineral liquid fuels produces enormous pollution problems, tomorrow hydrogen will solve all environmental problems due to road transports: but "how we can go from today to tomorrow?"

Natural gas-hydrogen blends may be a potential bridge for this transition.