# POTENTIAL MODELS FOR STAND-ALONE AND MULTI-FUEL GASEOUS HYDROGEN REFUELLING STATIONS: ASSESSMENT OF ASSOCIATED RISK

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**ABSTRACT**

Air pollution and traffic congestion are two of the major issues affecting public authorities, policy makers and citizens not only in Italy and European Union but worldwide; this is nowadays witnessed by always more frequent limitations to the traffic in most of Italian cities, for instance.
Hydrogen use in automotive appears to offer a viable solution in medium-long term; this new perspective involves the need to carry out adequate infrastructures for distribution and refuelling, and consequently the need to improve knowledge on hydrogen technologies from a safety point of view.
In the present work possible different configurations for gaseous hydrogen refuelling station has been compared: "stand-alone" and "multi-fuel".
These two alternative scenarios has been taken into consideration, each of one with specific hypotheses:
"stand-alone" configuration, based on the hypothesis of a potential model consisting of a hydrogen refuelling station composed by on-site hydrogen production via electrolysis, a trailer of compressed gas for back-up, compressor unit, intermediate storage unit and dispenser. In this model it is assumed that no other refuelling equipment and/or dispenser of traditional fuel is present in the same site.
"multi-fuel" configuration, where it is assumed that the same components for hydrogen refuelling station are placed in the same site beside one or more refuelling equipment and/or dispenser of traditional fuel.
Comparisons have been carried out from the point of view of specific risk assessment, which have been conducted on both the two alternative scenarios.

## 1.0 DESCRIPTION OF MODELS ANALYZED

### 1.1 Model No. 1-"stand-alone"

Main <u>components</u> included and analysed in "stand-alone" configuration were:

- Electrolyzer unit (Fig. 1): alkaline typology (presence of a liquid electrolyte consisting of a water mixture with KOH @ 30% weight). Electrolyzer is equipped with deoxo unit for additional purification of hydrogen up to 99,995%. All the Electrolyzer components (cell stack, separators, deoxo unit, power and control electrical board) are installed inside a ventilated container, equipped with fan and hydrogen sensors and positioned out-door. Outside the container it is placed an equalizer vessel from which hydrogen is transferred to compressor.

- Hydrogen trailer (fig. 2): it includes N. 15 cylinders (single water capacity 1570 lt.) @ $2.0 *10^7$ Pa operating pressure; it may supply back-up gas for vehicles when Electrolyzer unit is out of service and/or in maintenance.

- Compressor unit (Fig.3): it consists of a three-stage reciprocating type and compresses hydrogen coming from production unit (or trailer) to maximum discharge pressure requested by refuelling; main data are max flow rate: 940 Nm3/h; inlet gas pressure range: $3.9*10^5 \div 2.0*10^7$ Pa; max. discharge pressure: $2.5*10^7$ Pa.

- Intermediate storage (Fig. 4): compressed hydrogen is stored in a high-pressure buffer bundle, made of No. 15 cylinders (single water capacity 85 lt.) @ $2.5*10^7$ Pa operating pressure and horizontally assembled; function of such a buffer is to have HP hydrogen ready for quick refuelling of a vehicle, while compressor works to compensate pressure loss of the HP section which happens during refuelling.

- Dispenser (Fig.5): single-hose type is considered, with maximum allowable fill pressure of $2.0*10^7$ Pa. Refuelling is allowed by connecting the end coupling to vehicle; dispenser flexible hose has a length of 3 m.

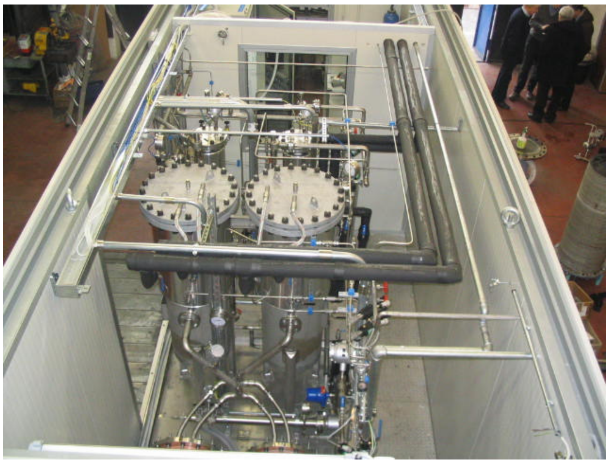

Figure 1. Electrolyzer unit (container)

Figure 2. Hydrogen trailer

Figure 3. Compressor unit

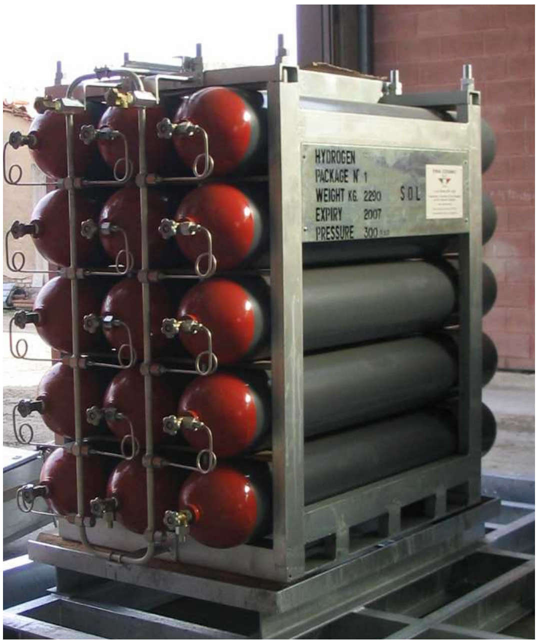


Figure 4. Intermediate storage


Figure 5. Dispenser

Two different concept alternatives (respectively with H2 produced on-site and externally delivered) were assumed for the stand-alone model of refuelling station.

Main work phases may be divided from a risk-analysis point of view as follows:

a) Hydrogen flow to vehicle from dispenser – refuelling start

b) Hydrogen flow to dispenser from intermediate storage

c) Hydrogen flow to intermediate storage, and dispenser, through compressor

d) Hydrogen production (through electrolyser) or back-up suuply (through trailer)

Layout (Fig. 6) assumed for the model foresees a separation between a “production/storage zone”(including electrolyser, compressor, back-up trailer and intermediate storage) and a “filling zone” (including dispenser and vehicle).
All equipment are installed outdoor; the electrolyzer unit is installed inside a close metallic container provided with a forced-ventilation system, which is also used to dissipate system heat.
Compressor, intermediate storage and dispenser equipment can be placed inside either a metallic cabinet or a different carter made of fireproof fibreglass: these carters foresee openings for natural ventilation equal to 10% minimum of base-surface, and are designed for atmospheric protection and not to ensure containment in case of explosion.
In addition, a gas detector is installed inside the compressor cabinet to shut-down the unit in case of leakages detection.
Hydrogen trailer is placed inside a concrete box equipped with gas detector which enables water sprinklers activation in case of leakages (10% LEL); concrete box ensures lateral and top coverage of trailer (see Fig.2).

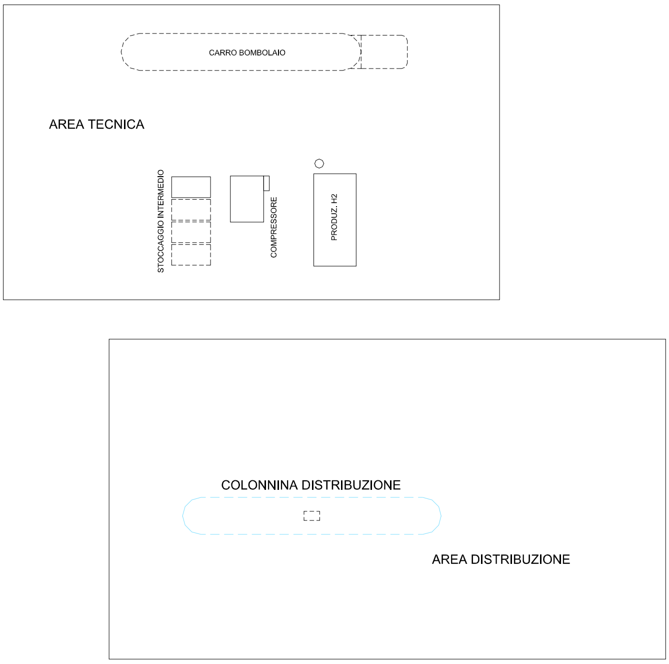


Figure 6. Layout (production/storage zone and filling zone)

Purpose of the Risk Analysis assessment has been to calculate proper safety distances between these two zones, as well as between components inside each zone, to evaluate need of requirements for additional explosion-protection measures and to confirm the feasibility of above configuration.

### 1.2 Model No. 2-“multi-fuel”

Main <u>components</u> included in “multi-fuel” configuration were:

-No. 1 hydrogen refuelling system including same components (of same size) above seen at chapter 1.1

-No. 1 natural gas refuelling system including typical components of an Italian plant (allowed filling pressure is 2,2 $*10^7$ Pa): pressure reduction cabinet, compressor room, cylinders room, dispenser.

-No. 1 gasoline refuelling system including typical components of an Italian plant: underground storage tank, trailer connection devices, dispenser.

Another purpose of the Risk Analysis assessment has been to calculate the level of risk associated to the “overlapping of effects” deriving from the proximity of different fuels, in order to calculate proper safety distances to minimize risk of incompatibility.

## 2.0 METHODOLOGY OF ASSESSMENT OF ASSOCIATED RISK

Purpose of the analysis has been to evaluate the associated risk involved with the examined configurations in order to:

-define an acceptable level of safety in hydrogen application during the operating phase;

-quantify the level of risk for potentially dangerous accidents (with regards to operators, people, equipment, environment etc...);

-identify safety distances between critical elements and boundaries of installation depending on quantities of hydrogen (and other traditional fuels) which are present inside the installation;

-evaluate the level of compatibility between traditional refuelling equipment and new hydrogen refuelling equipment;

-identify which lay-out model is most suitable to ensure what above;

-suggest potential recommendation for new standards

A Risk Analysis approach was conducted on each of the two models, according to guidelines provided in D.M. 20/10/98 [1] (reference for flammable liquids, e.g. gasoline) and - more in general - in D.P.C.M.31/03/89 [2].

The Risk Analysis consists on the following steps as described below:

- Historical analysis, including investigation on accidents occurred in past involving the same chemicals and in similar plants (Data base MHIDAS - Major Hazard Incident Data Service - Health & Safety Executive, UK);
- HAZOP (HAZard OPerability) analysis, including investigation on causes leading to deviation of process parameters, possible relevant consequences and prevention/mitigation measures in place order to prevent/mitigate the consequences;
- Identification of top events - based on the HAZOP results – leading to chemical release to the atmosphere;
- Calculation of likelihood for each of the top events identified using fault tree analysis;
- Evaluation of expected incidental scenarios and calculation of the relevant effects (Software EFFECTS 2, based on the international recognized TNO - Methods for the calculation of physical effects resulting from releases of hazardous materials).

Safety distances have been identified in accordance with the definition of limit values for domino effect provided by D.M. 20/10/98.

For methane stations reference is made to D.M. 24/11/84 [3], D.M. 24/05/2002 [4] and subsequent D.M. 28/06/2002 [5].

## 3.0 RESULTS AND RELEVANCE WITH RESPECT TO HYDROGEN SAFETY

For **Hydrogen "stand-alone" configuration** (in which $H_2$ quantities are lower than limits specified in D.Lgs. n° 334 del 17/08/1999 [6]), risk analysis top event results identify following different potential incidental scenarios:

Electrolyzer unit: hydrogen release through safety valve, and catastrophic pipe rupture;

Back-up trailer: hydrogen leakage from cylinders valves, and catastrophic rupture of valve(s);

Intermediate storage: hydrogen leakage from cylinders valves, and catastrophic rupture of valve(s);

Line from compressor unit: hydrogen release through safety valves

Dispenser: hose incidental rupture

Calculations show the following:

Modelling developed in the study have identified the **hydrogen trailer** and the **intermediate storage** as the most critical element in term of potential risk.

Based on the calculation results, distances that shall be kept between the source of release (valves of the intermediate storage) and the next component in the jet direction are:

23 m for the trailer (back side equipped where cylinders valves are installed),

11 m for the intermediate storage (back side equipped where cylinders valves are installed);

This safety distance is associated to the domino effect radiation value relevant to the jet-fire in case of catastrophic release and immediate ignition.

Due to minor hold-up or lower pressure, consequences related to all the other Hydrogen releases can be considered not relevant.

Even if analysis developed do not highlight any specific requirement, it is assumed to guarantee 8 m distance between the technical area and the dispenser to ensure safe contemporary passage of two trucks also in case of release from hose during refilling (Lower Explosivity Limit is reached within 7 m from sources of release).

For **"multi-fuel" configuration**, risk analysis resulting from traditional fuels analyzed (natural gas and gasoline) shows interesting behaviours especially for what applies to gasoline.

<u>Natural gas</u>

Distances identified in DM 24/05/2002 for natural gas station components are summarized here below:

Table 1: Natural gas station – Safety distances

| Component | Protection distance (m) | Internal safety distance (m) | External safety distance (m) |
|---|---|---|---|
| Reduction and measurement | 2 | 10 | 10 |
| Compressors | 10 | 10 | 20 |
| Intermediate storage | 5 | - | 20 |
| Dispenser | 10 | 8 | 20 |

<u>Gasoline</u>

Historical data analysis identified the truck unloading station and the gasoline truck itself as the most critical component.

In case the station is located in open space and confinement of released vapours is not possible, calculation results show that domino effect values for pool fire (12, 5 kW/m2) and for unconfined vapour cloud explosion (3 *$10^4$ Pa) are reached within 22 m from the source of release.

## 4.0 CONCLUSIONS

Conclusions concerning **“stand-alone”** model are the following:

Unification into a same “production/storage zone” of electrolyzer, trailer, intermediate storage and compressor is not conceptually precluded provided that critical elements (back side of trailer and intermediate storage) are placed in a way that them cannot impinge the others and safety distances required by sources of release are guaranteed;

Unification into a same module or area of compression equipment and intermediate high-pressure buffer is not conceptually precluded form a safety point of view;

More than one intermediate storages could be grouped together provided that they are aligned and a jet fire from one of them cannot impinge the others and safety distances required by sources of release are guaranteed;

Regarding “filling zone”, it has been assessed that dispenser has minimal impact in the definition of the potentially expected incidental scenarios, due to lower hydrogen quantities involved. As additional measure, 8 m distance could be kept between dispenser and technical area to ensure safe contemporary passage of two trucks.

Safety distances resulting from specific calculations are well in line with prescriptions of applicable laws.

Conclusions concerning **“multi-fuel”** model are the following:

Safety distances resulting from specific calculations for hydrogen are comparable with the same ones provided for natural gas (in same conditions).

Safety distances resulting from specific calculations for hydrogen in comparison with available historical data and evaluations conducted on gasoline traditional stations, show in practice a major criticality of “gasoline equipment” (higher safety distances resulting from calculations) in respect to “hydrogen equipment” ((higher safety distances resulting from calculations).

In order to reduce distance identified for gasoline unloading station (22 m) additional protection measure should be adopted during design and operation, to mitigate effects of radiation in due to fire and overpressure due to unconfined vapour cloud explosion and hence could be reduced.

A final summary-table of safety distances for “multi-fuel configurations results as follows:

Table 2: Multi –fuel configuration station – Safety distances

| Fuel 1 / Fuel 2 | Internal Safety Distance between stations (m) | Internal Safety Distance between dispensers (m) | External Safety Distance (m) |
|---|---|---|---|
| Hydrogen / Methane | 11 | 8 | 20 (H2) / 11 (Methane) |
| Hydrogen / Gasoline | 22 | 22 | 22 (H2) / 11 (Gasoline) |

Note: distances do not consider mitigation measures

## REFERENCES


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