Notes

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Hydrogen can be liquefied only, when cooled to at least –240 °C. Below this critical temperature the gas can be liquefied by compression. Liquefaction at atmospheric pressure is reached at –253 °C (boiling temperature).
The relative density of cold hydrogen gas is 1,11 so that gas, generated from liquid hydrogen, spreads first in more or less horizontal direction. With progressing warming the gas becomes lighter than air.
The relative density of liquid hydrogen, compared with water, is 0,07. So it is a very light liquid.
Liquid hydrogen, when released to the atmosphere, evaporates very quickly. The level of a liquid hydrogen pool due to evaporation drops down by 2,5 – 5 centimeter per minute.
The evaporation of 1 litre liquid hydrogen yields roughly 50 litre cold gas. When the gas warms up to ambient temperature its volume increases to roughly 830 litre.

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Hydrogen is a flammable gas, which burns in air with very high combustion velocity.
The combustion product of hydrogen is water ($2H_2 + O_2 \rightarrow 2 H_2O$). The flame emits very little radiant heat and is colourless and almost invisible. For these reasons the hydrogen flame gives limited warning of its presence.
Hydrogen forms with air, oxygen or other oxidizing agents explosive mixtures, which can be ignited very easily.
Explosion characteristics of hydrogen / air mixtures at ambient temperature and pressure:
Lower explosion limit: 4,0 Vol% H_2 Upper explosion limit: 75,6 Vol% H_2
Ignition temperature: 560 °C. (Comment: The ignition temperature of hydrogen is relatively high, compared with other flammable gases.)
Minimum ignition energy: 0,019 milliJoule. (Comment: The minimum ignition energy of hydrogen is relatively low compared with other flammable gases).
Explosion limits of hydrogen / oxygen mixtures at ambient temperature and pressure:
Lower explosion limit: 4,6 % H_2 Upper explosion limit: 93,9 % H_2
Hydrogen does not impose a danger to the environment. It doesn´t harm the ozone layer and doesn´t contribute to the green house effect. The combustion exhaust gas of hydrogen does not contain carbon dioxide or soot. Missing soot is also the reason why the hydrogen flame is colourless and in the daylight almost invisible.

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Hydrogen embrittlement and stress corrosion are complicated processes, depending on numerous factors, such as
Temperature and pressure of hydrogen
Contaminants in hydrogen
Kind of metallic material
Structure of metallic material (e.g. presence of discontinuities)
Stress distribution in the material

Advice for the trainer:
Don´t discuss this subject in more detail, unless you have studied relevant chapters in the EIGA documents
IGC Doc. 15 /96 „Gaseous hydrogen stations“
IGC Doc. 121/04 „Hydrogen transportation pipelines“

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Hydrogen is not toxic but can act as a simple asphyxiant by displacing or diluting atmospheric air to the point where the oxygen content cannot support life. Unconsciousness without any warning symptoms can occur from inhaling pure hydrogen or air that contains more than 20 Vol% hydrogen. However the lower explosion limit – 4 Vol% hydrogen in air – is reached before the asphyxiant hazard level is achieved. Therefore the fire hazard of hydrogen far exceeds the asphyxiation hazard.

Liquid hydrogen and the cold gas evolving from the liquid can produce severe cryogenic burns upon contact with the skin and other tissues. The eyes can be injured even by short exposure to the

cold gas or splashed liquid. Contact between unprotected parts of the body with uninsulated installation containing liquid hydrogen can cause the flesh to stick and tear when an attempt is made to withdraw.

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Various terms for the same thing:
Cryogenic gas – Term which is usually used in EIGA documents.
Cryogenic liquid – Term which is usually used in CGA documents.
Refrigerated liquefied gas – Term which is used in the international transport regulation for dangerous goods (ADR).
Various definitions for the same thing:
CGA, Handbook of compressed gases: Cryogenic liquids are gases that have been transformed by refrigeration into extremely cold liquids which are stored at temperatures below –90 °C.
ADR: Refrigerated liquefied gas: A gas which when packaged for carriage is made partially liquid because of its low temperature.

Two essential characteristics of cryogenic gases:
The state of aggregation is liquid.
The temperature is extremely low, less than –100 °C.
Subject of the presentation are the cryogenic „air gases“ oxygen (LOX), nitrogen (LIN) and argon (LAR) and cryogenic hydrogen (LH2) and cryogenic helium (LHe).

Some other gases also can be transported and stored in cryogenic state, e.g. natural gas (LNG), ethylene, ethane and the rare gases neon, krypton, xenon.

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Gases in cryogenic state have the same chemical properties as in gaseous state.
A gas can be either inert or oxidizing or flammable. Each of these properties excludes the two other ones.
Nitrogen is a so-called inert gas, that reacts hardly or not at all with other substances.
Argon and helium belong to the rare gases (or noble gases), which are totally inert. Rare gases don´t react with other substances.
Oxygen is oxidizing = fire promoting, but non-flammable. Oxygen promotes intensively any combustion. Substances that are nonflammable in air, e.g. metals, can burn vigorously with oxygen.
Hydrogen is flammable and can burn explosively not only with air or oxygen but also with other oxidizing substances, such as chlorine or nitrogen oxides.

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A special physiological effect of all cryogenic gases results from their low temperature, which is absolutely incompatible for human beings. On contact of the human skin with cold liquid or non-insulated cryogenic installation frostbites or cold burns arise, which are serious and sometimes fatal. The risk increases with intensity of contact.
None of the mentioned gases is toxic or narcotic.
Nitrogen, argon, helium and hydrogen have no physiological effect. When these gases are inhaled together with sufficient oxygen the health is not endangered. But these gases don´t support live. When they are inhaled without sufficient oxygen the risk of asphyxiation arises.
Note: Asphyxiation is not due to any effect of the asphyxiant gas but it is caused exclusively by the missing oxygen.
For asphyxiant gases – contrary to the toxic gases – there are no figures of admissible concentration at the working place. The only essential gas for human life is oxygen. Without sufficient oxygen human beings can survive for maximum three minutes.

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The air gases are mainly produced in large cryogenic air separation units (Gas production centre) and we supply gases directly to a customer through a pipeline or in liquid form to customer tanks or to filling stations to be filled into cylinders for end users.
We also produce air gases in non-cryogenic on-site plants (adsorption and membrane technology) where the products go directly into the customer's plant.