

CGA H-4—2020

**TERMINOLOGY ASSOCIATED
WITH HYDROGEN FUEL
TECHNOLOGIES**

THIRD EDITION

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NOTE—Technical changes from the previous edition are underlined.

NOTE—Appendix A (Informative) is for information only.

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1 Introduction

As hydrogen fuel use becomes more prevalent, terms previously encountered primarily in specialty fields will enter into widespread usage. Additionally, other terms have definitions different from normal usage. Use of consistent terminology would be beneficial.

2 Scope and purpose

2.1 Scope

This publication provides a description of the technologies and terminology as they apply to hydrogen fuel production, storage, transport, and use.

2.2 Purpose

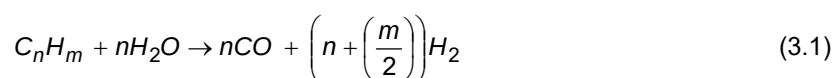
This publication is a single source of uniform terminology for hydrogen fuel technologies. This publication will be useful to persons involved with hydrogen production, storage, transport and use technologies, regulators, and codes and standards developers.

3 Technology descriptions

3.1 Production

3.1.1 Steam reformation

Steam reformation is a chemical reaction between hydrocarbons and steam with the assistance of catalysts to produce hydrogen and carbon monoxide according to the following equation:

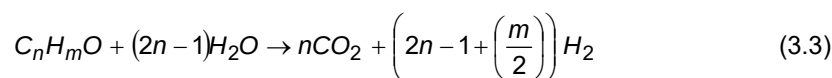


The reactions are typically endothermic and kinetically favorable at high temperatures between 1000 °F and 1500 °F (537.8 °C and 815.6 °C). The steam reforming reaction is typically coupled with a lower temperature, exothermic reaction called water gas shift (WGS) to convert the carbon monoxide to carbon dioxide and produce more hydrogen according to the following equation:



The product gases then pass through a pressure swing adsorption (PSA) bed to purify the hydrogen product. The product hydrogen's purity is typically 99.99% or greater at the end of the purification process. When natural gas or methane is used for the feed, the process is called steam methane reforming (SMR). Figure 1 is a schematic of SMR.

When alcohol is used as a feed, the steam reforming reaction occurs according to the following equation:



As with equation 3.2, the product gases pass through a PSA bed where the hydrogen gas is purified.

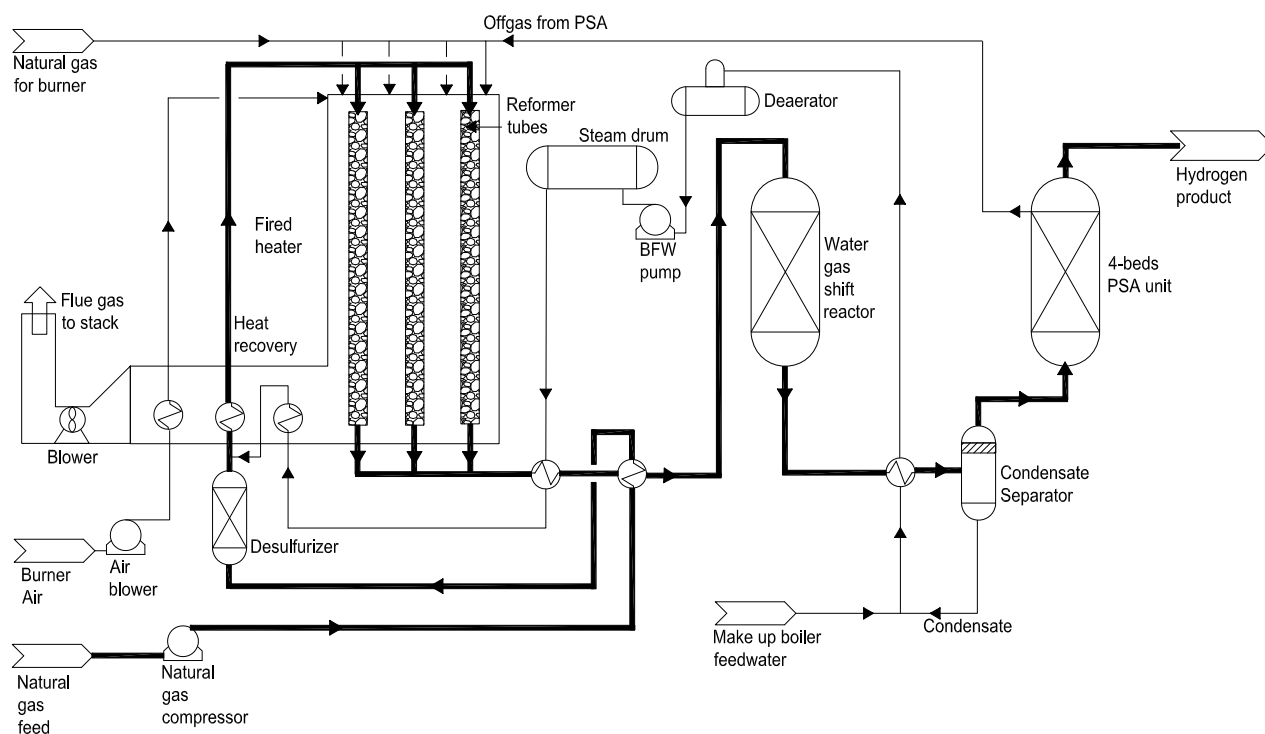
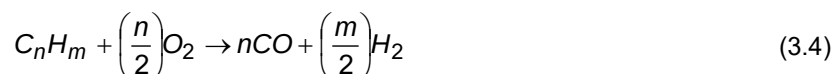


Figure 1—Steam methane reforming (SMR) schematic

3.1.2 Partial oxidation

Partial oxidation is an incomplete combustion reaction where hydrocarbons or hydrogen-containing compounds are reacted with a substoichiometric amount of oxygen to produce a mixture of hydrogen and carbon monoxide. The reactions are highly exothermic and follow the equation:



When the reactions are assisted by the use of catalyst, they are called catalytic partial oxidation (CPOX). CPOX has the advantage of a lower reaction temperature, the ability to use air as oxidant, shorter reaction times, and thus a smaller reactor.

3.1.3 Autothermal reformation

Autothermal reformation is a combination of highly exothermic partial oxidation and endothermic steam reforming reactions. It integrates the heat produced by the partial oxidation reactions and uses it to sustain the steam reforming reactions. The products of the reactions are mixtures of hydrogen and carbon monoxide. When the reactions are balanced, the process only requires heat input during the initial stage. Once a steady state is achieved, external heat input is not required to sustain the reactions.

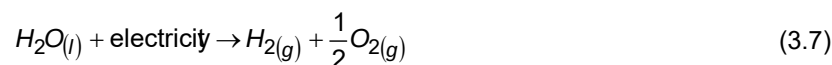
3.1.4 Gasification

Gasification is a chemical reaction that produces hydrogen by injecting steam into a hot bed of coal. Similar to the steam reforming process, the reaction is coupled with a WGS reaction to produce more hydrogen according to the following equations:



3.1.5 Electrolysis

Electrolysis is an electrochemical process that uses electricity to separate water molecules into gaseous hydrogen and oxygen according to the following equation:



The reaction at the anode proceeds according to the following equation:



The reaction at the cathode proceeds according to the following equation:



The electrolysis process requires energy for the dissociation of water plus the energy to expand the produced gases. The change in internal energy is accompanied by the expansion of the gases produced, so a change in enthalpy represents the necessary energy to accomplish the electrolysis. However, it is not necessary to put in the entire amount in the form of electrical energy. Since the entropy increases in the process of dissociation, the energy can be supplemented from the environment. The amount that shall be supplied by the power source is known as the Gibbs free energy.

Another governing equation for water electrolysis (from the Nernst equation) is:

$$\Delta E = \Delta E^0 - \frac{RT}{2F} \ln Q \quad (3.10)$$

Where:

R = Universal gas constant

T = Temperature (absolute)

F = Faraday's constant

Q = Reaction quotient

The cell potential is calculated by equation 3.10.

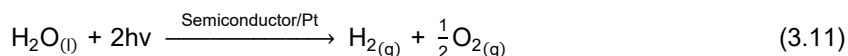
Unipolar or monopolar electrolysis cells are connected in series/parallel as needed. They are of standard industrial design based on the Bacon Cell. Typically, they are used on large systems as they are more economical.

Bipolar electrolysis cells (filter press) consist of repeating membrane electrode assemblies and conductive plates connected in series. They are very similar to proton exchange membrane (PEM) fuel cells in construction since a fuel cell is an electrolyzer run in reverse. Conductive plates are bipolar with a cathode on one side and an anode on the other side for the next cell. The cell also contains conduits or channels for fluid management.

The theoretical efficiency of the electrolysis process is $\eta = \text{LHV}/\Delta G$, and the real efficiency is $\eta = \text{LHV}/\text{Total Power In}$ (LHV = hydrogen lower heating value [noncondensing]). Manufacturers often report efficiencies versus ideal separation voltage or in theoretical terms defined previously as these efficiencies can be as high as 96%. The typical system power demand is 0.13 kWh/scf to 0.18 kWh/scf (4.6 kWh/Nm³ to 6.4 kWh/Nm³).

3.1.6 Photoelectrolysis

Photoelectrolysis is a process used to produce hydrogen by splitting water using solar energy. The solar radiation activates the surface of a semiconductor that is in contact with water and generates electrical current to carry out the electrolysis process directly according to the following equation:



3.2 Storage and transportation

3.2.1 Compressed gas storage and transportation

One of the simplest ways to transport and store hydrogen is in gaseous form. Gaseous hydrogen can be compressed to 15 000 psi (103 MPa). In general, gas transportation and storage is not as efficient as liquid hydrogen transportation and storage. Because hydrogen is so light in weight compared to the storage containers, the weight of hydrogen is typically 4% or less of the cargo weight.

More details about the properties of gaseous hydrogen can be found in CGA G-5, *Hydrogen* [1].¹

Gas hydrogen is transported and/or stored in four modes:

- cylinders—transportation and storage;
- tube trailers—transportation and storage;
- receivers—storage; and
- pipelines—transportation.

Each option has advantages and disadvantages, which are discussed in the following sections.

3.2.1.1 Cylinders

A cylinder is a compressed gas container, cylindrical in shape and of varying sizes.

- Cylinders for transporting compressed gases are regulated in the United States by Department of Transportation (DOT) regulations and in Canada by Transport Canada (TC) regulations [2, 3]. Each agency has a set of regulations governing the transportation of hazardous materials (DOT) or the transportation of dangerous goods (TC). The terminology is slightly different, but the intent is the same: to protect the public from hazardous/dangerous materials on the highway or in other modes of public transportation. These cylinders are shipped and delivered to customer locations; and
- Cylinders used as part of the integrated onboard vehicle fuel system are regulated in the United States by DOT National Highway Traffic Safety Administration (NHTSA) with reference to ANSI/CSA HGV2, *Compressed Hydrogen Gas Vehicle Fuel Containers* or in Canada by Transport Canada with reference to CSA B51, *Boiler, pressure vessel, and pressure piping code* [4, 5].

3.2.1.1.1 DOT/TC cylinders

DOT and TC regulations have specifications for cylinders and other vessels. Only certain specification containers may be used for hydrogen. Two materials are used for hydrogen cylinders: steel and aluminum. The specifications are as follows:

- Seamless steel cylinders:
 - DOT specifications 3A or 3AA
 - TC specifications 3AM or 3AAM; and

¹ References are shown by bracketed numbers and are listed in order of appearance in the reference section.

- Seamless aluminum cylinders:
 - DOT specification 3AL
 - TC specification 3ALM.

Cylinder designations vary from one industrial gas supplier to another. What one supplier calls a “K” cylinder can be called a “T” cylinder by another company. It is necessary to consult with the industrial gas supplier for specific cylinder details or to find this information at company websites and cylinder catalogs. Industrial gas suppliers often have tables of their cylinders and ones from other suppliers for comparison purposes. Typical cylinder service pressures run from 2000 psi to 3600 psi (13 790 kPa to 24 820 kPa)² and contents range from 65 scf to 484 scf (1840 L to 13 700 L) of hydrogen.

The following publications contain more details about the proper handling of cylinders:

- CGA P-1, *Standard for Safe Handling of Compressed Gases in Containers* [7];
- CGA P-22, *The Responsible Management and Disposition of Compressed Gases and Their Cylinders* [8]; and
- CGA PS-7, *Safe Transportation of Compressed Gas Cylinders and Cryogenic Liquid Containers in Passenger Vehicles* [9].

The main advantage of cylinders is they are small and easy to transport. They can be joined together to supply more product than is available from one cylinder. The drawback to cylinders is that they are small and do not hold a large amount of product. The largest cylinder listed previously holds only 484 scf (13 700 L) of hydrogen. Using large amounts of hydrogen requires frequent cylinder change-out, which is generally time consuming and more costly.

Generally, the industrial gas supplier delivers the required number of cylinders (single or multiple cylinder packs) and replaces them with new cylinders as they are emptied of product. Valving is usually arranged so the new cylinders are connected to the use point before the old cylinders are removed.

DOT requires that the industrial gas supplier responsible for filling the cylinder obtain the permission of the cylinder owner before filling any DOT authorized cylinder. A cylinder that is past its requalification or inspection date shall not be filled. The interval between inspections or requalifications is typically 5 years. The interval may be longer for cylinders that are of a different design type or regulated differently (such as by a special permit). The cylinder owner is responsible to make sure the cylinder is requalified according to regulatory requirements.

3.2.1.1.2 HGV2/B51 cylinders

Cylinders meeting the specifications of ANSI/CSA HGV2 or CSA B51 are designed, built, and tested to be used as fuel storage containers for vehicles utilizing hydrogen gas [4, 5].

3.2.1.2 Tube trailers

A tube trailer is another portable delivery and storage system. It consists of larger diameter seamless steel cylinders mounted on a chassis to form a bulk gas trailer. The tubes shall be built to the same DOT and TC specifications required for cylinders:

- DOT specifications 3AX or 3AAX; and
- TC specifications 3AXM or 3AAXM.

The tubes come in two sizes and are typically 35 ft (11 m) in length:

- small diameter tubes that are 9 in (23 cm) in diameter; or
- large or jumbo tubes that are 22 in (56 cm) in diameter.

² kPa shall indicate gauge pressure unless otherwise noted as (kPa, abs) for absolute pressure or (kPa, differential) for differential pressure. All kPa values are rounded off per CGA P-11, *Guideline for Metric Practice in the Compressed Gas Industry* [6].