CH2356 Energy Engineering

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Hydrogen – as an Energy Carrier

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Introduction

- Hydrogen is the simplest and most abundant chemical element in our universe—it is the power source that fuels the Sun and its oxide forms the oceans that cover three quarters of our planet. This ubiquitous element could be part of our urgent quest for a cleaner, greener future.

- Hydrogen, in association with fuel cells, is widely considered to be pivotal to our world's energy requirements for the twenty-first century and it could potentially redefine the future global energy economy by replacing a carbon-based fossil fuel energy economy.

Introduction (contd.)

- Hydrogen is consumed by a pollution-free chemical reaction--not combustion--in a fuel cell. The fuel cell simply combines hydrogen and oxygen chemically to produce electricity, water, and waste heat.

- Hydrogen has often been called the perfect fuel. Its major reserve on earth (water) is inexhaustible. The use of hydrogen is compatible with nature, rather than intrusive. We will never run out of hydrogen.

Hydrogen Based Economy

- The ultimate realization of a hydrogen-based economy could confer enormous environmental and economic benefits, together with enhanced security of energy supply. However, the transition from a carbon-based (fossil fuel) energy system to a hydrogen-based economy involves significant scientific, technological, and socio-economic barriers. These include:

  - low-carbon hydrogen production from clean or renewable sources;
  - low-cost hydrogen storage;
  - low-cost fuel cells;
  - large-scale supporting infrastructure, and
  - perceived safety problems.

Hydrogen

- Hydrogen gas is lighter than air and, as a result, it rises in the atmosphere. This is why hydrogen as a gas (H_2) is not found by itself on earth. It is found only in **compound** form with other elements.
- Hydrogen combined with oxygen, is water (H_2O). Hydrogen combined with carbon, forms different compounds such as methane (CH_4), coal, and petroleum.
- Hydrogen is also found in all growing things—biomass. It is also an abundant element in the earth's crust.
- Hydrogen has the highest energy to weight ratio of all fuels.
- Water is made of 11.2 % hydrogen by weight.
- 1 kg of hydrogen contains the same amount of energy as 2.1 kg of natural gas or 2.8 kg of gasoline.

Properties of Hydrogen

- Gas density 0.09 kg/Nm^3
- Liquid density 71 kg/m^3
- Boiling point 20.4 K
- Lower Heating Value (LHV) 121 MJ/kg

Hydrogen – An Energy Carrier

- Energy carriers move energy in a usable form from one place to another. Electricity is the most well-known energy carrier.

- Like electricity, hydrogen is an energy carrier and must be produced from another substance. Hydrogen is not widely used today but it has great potential as an energy carrier in the future.

- Unlike electricity, large quantities of hydrogen can be easily stored to be used in the future. Hydrogen can also be used in places where it's hard to use electricity. Hydrogen can store the energy until it's needed and can be moved to where it's needed.

- Importantly, hydrogen can also be used as a storage medium for electricity generated from intermittent, renewable resources such as solar, wind, wave and tidal power, and biomass.

Hydrogen – An Energy Carrier (contd.)

- Historically the main reasons for promoting hydrogen as an energy carrier are its outstanding properties for environmental protection. Burning hydrogen with air under appropriate conditions in combustion engines or gas turbines results in very low or negligible emissions.

- Hydrogen originates from a primary source. If it is obtained from methane, methanol or a fossil fuel, the reforming process itself will results in carbon dioxide emissions. This carbon dioxide from the reforming process is highly concentrated, therefore making it much cheaper to recover than from diluted exhaust gases of gas turbines.

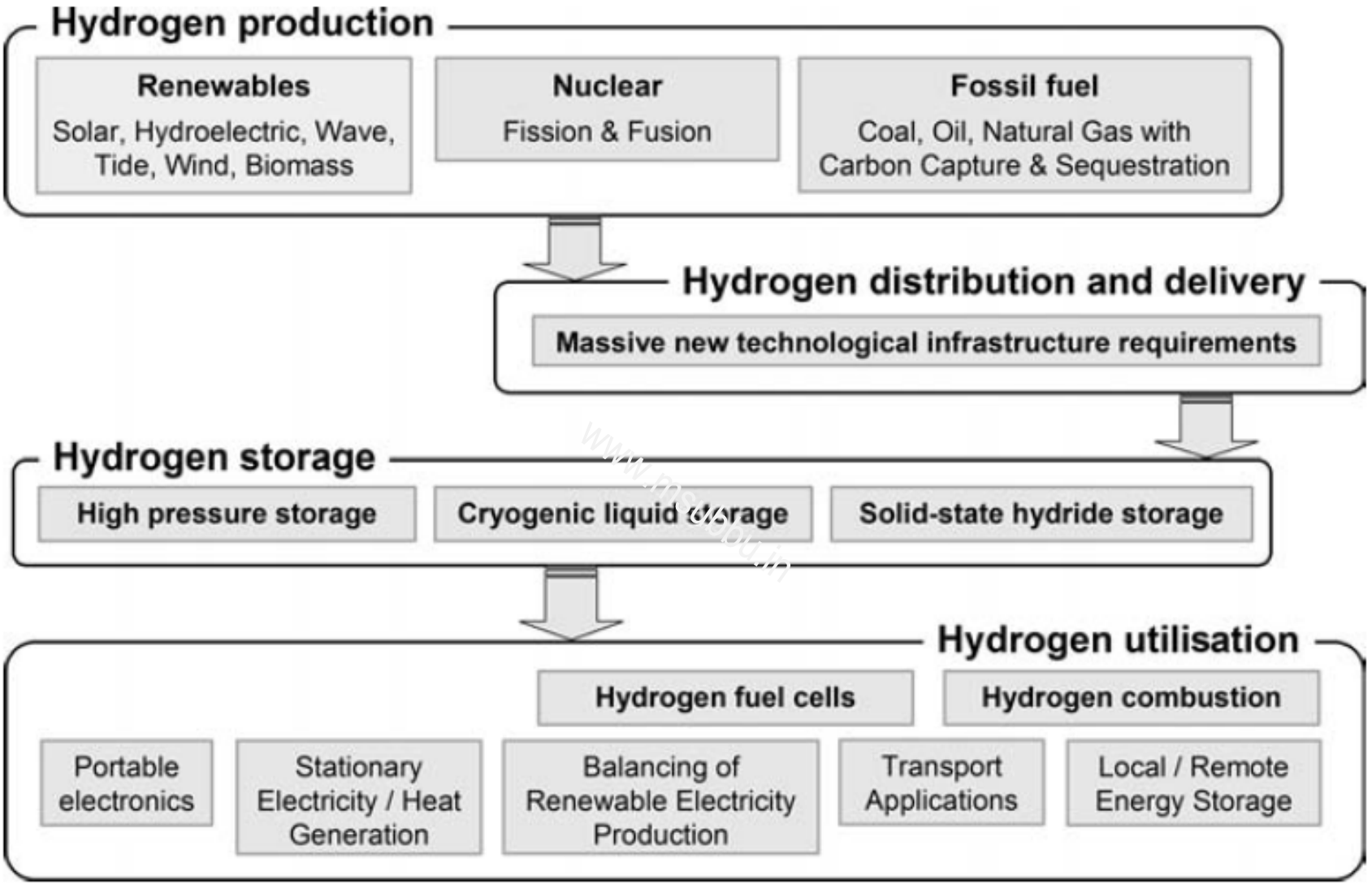

Figure 10.2 Hydrogen as an energy carrier linking hydrogen production methods to the end users.

Generating Hydrogen

- Since hydrogen doesn't exist on earth as a gas, we must separate it from other elements.
- We can separate hydrogen atoms from water, biomass, or natural gas molecules.
- The two most common methods for producing hydrogen are **steam reforming** and **electrolysis** (water splitting)

Hydrogen Use in Fuel Cells

- Today, there are an estimated 400 to 500 hydrogen-fueled vehicles in the U.S., mostly in California. Most of these vehicles are buses and automobiles powered by electric motors. They store hydrogen gas or liquid on board and convert the hydrogen into electricity for the motor using a **fuel cell**.
- Before hydrogen can play a bigger energy role and become a widely used alternative to gasoline, many new facilities and systems must be built.
- We will need facilities to make hydrogen, store it, and move it.
- We will need economical fuel cells. And consumers will need the technology and the education to safely use it.

Hydrogen Storage

Form of Hydrogen	Volume of H_2	Pressure	Temperature	Remarks
Molecular hydrogen	Max. 33 kg/m^3	800 bar	298 K	Composite cylinder
	71 kg/m3	1 bar	21 K	Liquid hydrogen
	20 kg/m3	70 bar	65 K	Physisorption
Atomic hydrogen	150 kg/m3	1 bar	298 K	Metal hydrides
	150 kg/m3	1 bar	298 K	Composite hydrides
	100 kg/m3	1 bar	298 K	Alkali + H_2O

Hydrogen Storage - Concerns

- Traditional storage options for hydrogen have centred upon high-pressure (up to 700 bar) gas containers or cryogenically cooled (liquefied) fluid hydrogen. One downside to these methods is a significant energy penalty—up to 20% of the energy content of hydrogen is required to compress the gas and up to 40% to liquefy it.

- Another crucial issue that confronts the use of high-pressure and cryogenic storage, centres on public perception and acceptability associated with the use of pressurized gas and liquid hydrogen containment. On-board storage of hydrogen is a formidable scientific and technological problem.

Hydrogen Storage - Concerns

- Hydrogen storage requires a major technological breakthrough and this is likely to occur in the most viable alternative to compressed and liquid hydrogen, namely the storage of hydrogen in solids or liquids. Metallic hydrides, for example, can safely and effectively store hydrogen within their crystal structure. Hydrogen is first 'sorbed' into the material and is released under controlled heating of the solid.

Table 10.1 Gravimetric (specific energy) and volumetric (energy density) energy content of various fuels, hydrogen storage options and energy sources (container weight and volume are excluded).

Fuel	Specific energy (kWh/kg)	Energy density (kWh/dm^3)
Liquid hydrogen	33.3	2.37
Hydrogen (200 bar)	33.3	0.53
Liquid natural gas	13.9	5.6
Natural gas (200 bar)	13.9	2.3
Petrol	12.8	9.5
Diesel	12.6	10.6
Coal	8.2	7.6
$LiBH_4$	6.16	4.0
Methanol	5.5	4.4
Wood	4.2	3.0
Electricity (Li-ion battery)	0.55	1.7

Source: Armstrong - Energy beyond Oil

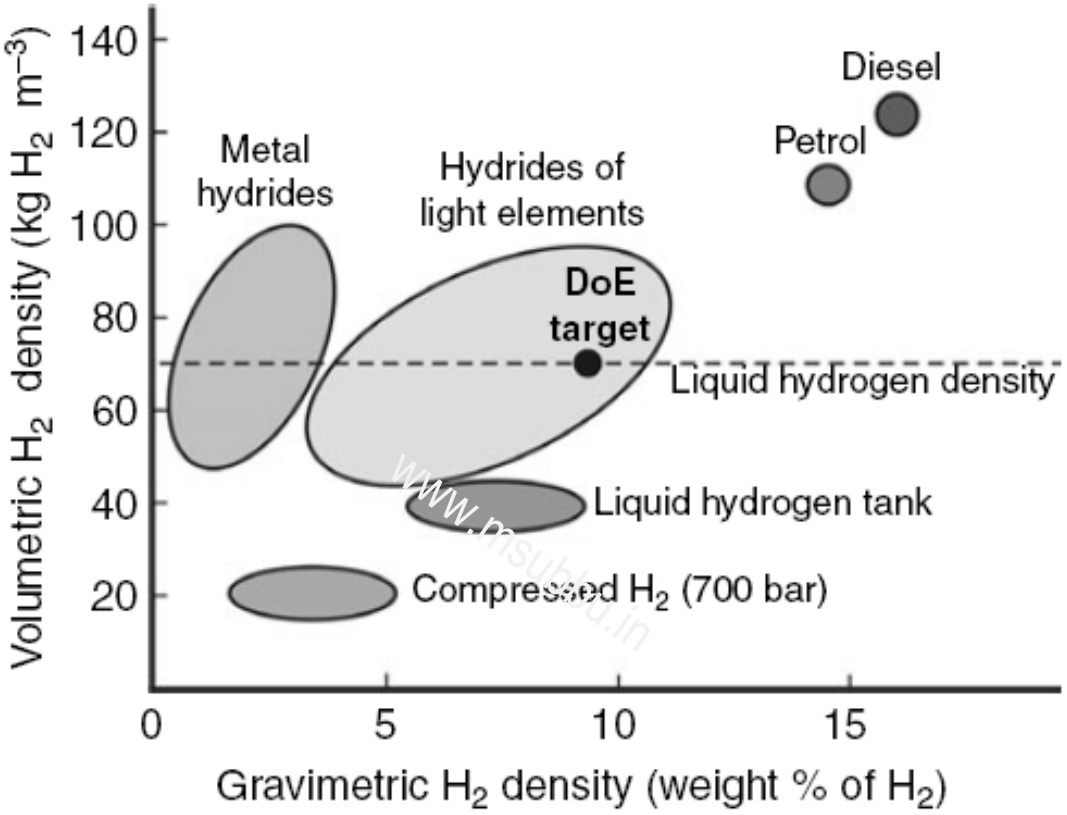

Figure 10.3 Gravimetric and volumetric densities of various hydrogen storage options (including weight and volume of the storage container). 'DoE target' represents the US Department of Energy target set for an 'ideal' hydrogen storage material. Metal hydrides are conventional, heavy metal hydrides such as $LaNi_5$ etc.