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**Department of Chemical engineering**

**CHE 441 ; Plant design and process Economics 1**

**Assignment 1**

**Group 2**

Write in detail, three process descriptions for hydrogen production.

Figure 1: Production of Hydrogen using waste heat boiler

Thermochemical cycles combine solely heat sources (thermos) with chemical reactions to split [water](https://en.m.wikipedia.org/wiki/Water%22%20%5Co%20%22Water) into its [hydrogen](https://en.m.wikipedia.org/wiki/Hydrogen%22%20%5Co%20%22Hydrogen) and [oxygen](https://en.m.wikipedia.org/wiki/Oxygen%22%20%5Co%20%22Oxygen) components. The term cycleis used because aside of water, hydrogen and oxygen, the chemical compounds used in these processes are continuously recycled. If [work](https://en.m.wikipedia.org/wiki/Work_%28thermodynamics%29%22%20%5Co%20%22Work%20%28thermodynamics%29) is partially used as an input, the resulting thermochemical cycle is defined as a hybrid one. The high temperatures necessary to split water can be achieved through the use of [concentrating solar power](https://en.m.wikipedia.org/wiki/Concentrating_solar_power%22%20%5Co%20%22Concentrating%20solar%20power) or waste heat boiler. [Hydrosol-2](https://en.m.wikipedia.org/wiki/Hydrosol-2%22%20%5Co%20%22Hydrosol-2) is a 100-kilowatt pilot plant at the [Plataforma Solar de Almería](https://en.m.wikipedia.org/wiki/Plataforma_Solar_de_Almer%C3%ADa%22%20%5Co%20%22Plataforma%20Solar%20de%20Almer%C3%ADa) in [Spain](https://en.m.wikipedia.org/wiki/Spain%22%20%5Co%20%22Spain) which uses sunlight to obtain the required 800 to 1,200 °C to split water. Hydrosol II has been in operation since 2008. The design of this 100-kilowatt pilot plant is based on a modular concept.

As a result, it may be possible that this technology could be readily scaled up to megawatt range by multiplying the available reactor units and by connecting the plant to [heliostat](https://en.m.wikipedia.org/wiki/Heliostat%22%20%5Co%20%22Heliostat) fields (fields of sun-tracking mirrors) of a suitable size.

Material constraints due to the required high temperatures are reduced by the design of a membrane reactor with simultaneous extraction of hydrogen and oxygen that exploits a defined thermal gradient and the fast diffusion of hydrogen. With concentrated sunlight as heat source/ waste heat boiler and only water in the reaction chamber, the produced gases are very clean with the only possible contaminant being water.





Figure 2: Steam-methane Reforming

Hydrogen production is the family of industrial methods for generating [hydrogen](https://en.m.wikipedia.org/wiki/Hydrogen%22%20%5Co%20%22Hydrogen). Hydrogen is primarily produced by [steam reforming](https://en.m.wikipedia.org/wiki/Steam_reforming%22%20%5Co%20%22Steam%20reforming) of [natural gas](https://en.m.wikipedia.org/wiki/Natural_gas%22%20%5Co%20%22Natural%20gas). Other major sources include naphtha or oil reforming of refinery or other industrial off-gases, and partial oxidation of coal and other hydrocarbons. A small amount is obtained by [water electrolysis](https://en.m.wikipedia.org/wiki/Electrolysis_of_water%22%20%5Co%20%22Electrolysis%20of%20water) and other sources.

Steam reforming is a mature production process in which high-temperature steam (700 °C–1,000 °C) is used to produce hydrogen from natural gas. Methane reacts with steam under 3–25 bar pressure in the presence of a catalyst to produce hydrogen, carbon monoxide, and the greenhouse gas carbon dioxide. For steam reforming to proceed, heat must be supplied to the process. In a separate reactor vessel, the carbon monoxide and steam are reacted using a catalyst to produce carbon dioxide and more hydrogen. In a final process step called "pressure-swing adsorption," carbon dioxide and other impurities are removed from the gas stream, leaving essentially pure hydrogen. Steam reforming can also be used to produce hydrogen from other fuels, such as coal and oil products.





Figure 3: Production of Hydrogen using Electrolysis

 The [Electrolysis](https://en.m.wikipedia.org/wiki/Electrolysis%22%20%5Co%20%22Electrolysis)of water is the [decomposition of water](https://en.m.wikipedia.org/wiki/Water_splitting%22%20%5Co%20%22Water%20splitting) into [oxygen](https://en.m.wikipedia.org/wiki/Oxygen%22%20%5Co%20%22Oxygen) and [hydrogen](https://en.m.wikipedia.org/wiki/Hydrogen%22%20%5Co%20%22Hydrogen) gas due to the passage of an [electric current](https://en.m.wikipedia.org/wiki/Electricity%22%20%5Co%20%22Electricity).

 This technique can be used to make [hydrogen gas](https://en.m.wikipedia.org/wiki/Hydrogen_gas%22%20%5Co%20%22Hydrogen%20gas), a key component of [hydrogen fuel](https://en.m.wikipedia.org/wiki/Hydrogen_fuel%22%20%5Co%20%22Hydrogen%20fuel), and breathable [oxygen](https://en.m.wikipedia.org/wiki/Oxygen%22%20%5Co%20%22Oxygen) gas, or can mix the two into [oxyhydrogen](https://en.m.wikipedia.org/wiki/Oxyhydrogen%22%20%5Co%20%22Oxyhydrogen) - also usable as fuel, though more volatile and dangerous. It is also called [water splitting](https://en.m.wikipedia.org/wiki/Water_splitting%22%20%5Co%20%22Water%20splitting). It ideally requires a [potential difference](https://en.m.wikipedia.org/wiki/Potential_difference%22%20%5Co%20%22Potential%20difference) of 1.23 [volts](https://en.m.wikipedia.org/wiki/Volt%22%20%5Co%20%22Volt) to split water.

A DC electrical power source is connected to two [electrodes](https://en.m.wikipedia.org/wiki/Electrode%22%20%5Co%20%22Electrode), or two plates (typically made from some inert metal such as [platinum](https://en.m.wikipedia.org/wiki/Platinum%22%20%5Co%20%22Platinum), [stainless steel](https://en.m.wikipedia.org/wiki/Stainless_steel%22%20%5Co%20%22Stainless%20steel) or [iridium](https://en.m.wikipedia.org/wiki/Iridium%22%20%5Co%20%22Iridium)) which are placed in the water. Hydrogen will appear at the [cathode](https://en.m.wikipedia.org/wiki/Cathode%22%20%5Co%20%22Cathode) (where [electrons](https://en.m.wikipedia.org/wiki/Electron%22%20%5Co%20%22Electron) enter the water), and oxygen will appear at the [anode](https://en.m.wikipedia.org/wiki/Anode%22%20%5Co%20%22Anode). Assuming ideal [faradaic efficiency](https://en.m.wikipedia.org/wiki/Faradaic_efficiency%22%20%5Co%20%22Faradaic%20efficiency), the [amount](https://en.m.wikipedia.org/wiki/Amount_of_substance%22%20%5Co%20%22Amount%20of%20substance) of hydrogen generated is twice the amount of oxygen, and both are [proportional](https://en.m.wikipedia.org/wiki/Proportionality_%28mathematics%29%22%20%5Co%20%22Proportionality%20%28mathematics%29) to the total [electrical charge](https://en.m.wikipedia.org/wiki/Electrical_charge%22%20%5Co%20%22Electrical%20charge) conducted by the solution. However, in many cells [competing side reactions](https://en.m.wikipedia.org/wiki/Electrolysis%22%20%5Cl%20%22Competing_half-reactions_in_solution_electrolysis%22%20%5Co%20%22Electrolysis) occur, resulting in different products and less than ideal faradaic efficiency.

[Electrolysis](https://en.m.wikipedia.org/wiki/Electrolysis%22%20%5Co%20%22Electrolysis) of pure water requires excess energy in the form of [over potential](https://en.m.wikipedia.org/wiki/Overpotential%22%20%5Co%20%22Overpotential) to overcome various activation barriers. Without the excess energy the electrolysis of pure water occurs very slowly or not at all. This is in part due to the limited [self-ionization of water](https://en.m.wikipedia.org/wiki/Self-ionization_of_water%22%20%5Co%20%22Self-ionization%20of%20water). Pure water has an [electrical conductivity](https://en.m.wikipedia.org/wiki/Electrical_conductivity%22%20%5Co%20%22Electrical%20conductivity) about one millionth that of seawater. Many [electrolytic cells](https://en.m.wikipedia.org/wiki/Electrolytic_cell%22%20%5Co%20%22Electrolytic%20cell) may also lack the requisite [electro catalysts](https://en.m.wikipedia.org/wiki/Electrocatalyst%22%20%5Co%20%22Electrocatalyst). The efficiency of electrolysis is increased through the addition of an [electrolyte](https://en.m.wikipedia.org/wiki/Electrolyte%22%20%5Co%20%22Electrolyte) (such as a [salt](https://en.m.wikipedia.org/wiki/Salt_%28chemistry%29%22%20%5Co%20%22Salt%20%28chemistry%29), an [acid](https://en.m.wikipedia.org/wiki/Acid%22%20%5Co%20%22Acid) or a [base](https://en.m.wikipedia.org/wiki/Base_%28chemistry%29%22%20%5Co%20%22Base%20%28chemistry%29)) and the use of [electro catalysts](https://en.m.wikipedia.org/wiki/Electrocatalyst%22%20%5Co%20%22Electrocatalyst).

Currently the [electrolytic process](https://en.m.wikipedia.org/wiki/Electrolysis%22%20%5Co%20%22Electrolysis) is rarely used in industrial applications since hydrogen can currently be produced more affordably from [fossil fuels](https://en.m.wikipedia.org/wiki/Fossil_fuel%22%20%5Co%20%22Fossil%20fuel).