

Hydrogen—what are the costs?

HPI operating facilities have many choices on how to meet their rising demand for H₂; here are several options

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Hydrogen is a commonly found element. For many petrochemical/chemical products, it is consumed as a process reactant or fuel. Currently, the global annual hydrogen demand is approximately 50 million tons (550 billion Nm³).

Bulk petrochemicals—ammonia and methanol—and processing/refining of gasoline consume nearly two thirds of the annual hydrogen demand. These facilities typically have hydrogen requirements up to 250,000 Nm³/h. The remaining hydrogen demand is directed to many different process industries including: fats and oils processing, chemicals, pharmaceuticals, metallurgy, semiconductor production and aerospace industries.

Growing demand. The hydrocarbon processing industries (HPI) are expanding their demand for hydrogen. Operating facilities can either buy hydrogen (H₂) or produce it. When manufacturing hydrogen for individual needs, several significant processes can produce hydrogen in quantities ranging from 50 to 4,000 Nm³/h. The technologies include: electrolysis of water, steam reforming and methanol cracking. With several differing options, operating facilities must consider which process is most cost-effective. Besides capital investment, operating costs and primary energy requirements should be evaluated by decision-makers. Several examples highlight key factors to consider when determining H₂ supply requirements.

Electrolysis. In the electrolysis process (Fig. 1), water is split according to the principle of:



In this process, H₂ is gained at the cathode with a purity of virtually 100% at atmospheric pressure; the contaminants are oxygen and water vapor. The utilities used in the process are electricity and demineralized water.

Depending on size, type and condition of the plant, the energy requirement to produce 1 Nm³ of H₂ by electrolysis ranges between of 4.2 to 5 kWh. Assuming an

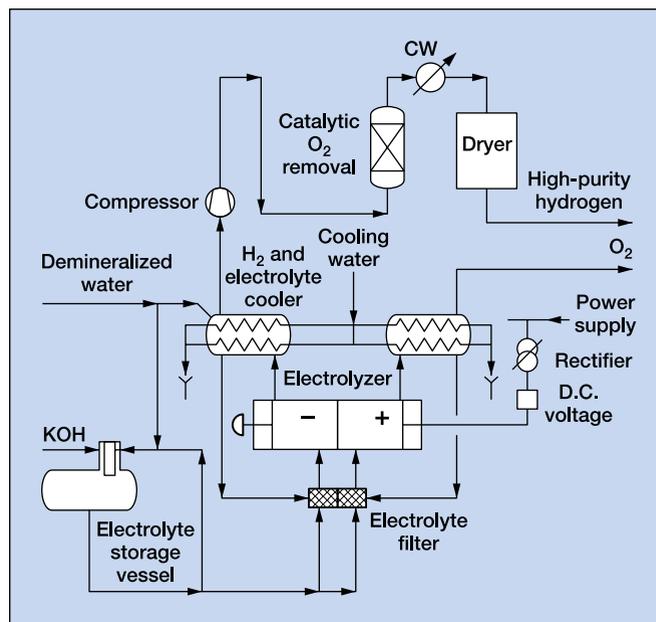


Fig. 1. Simplified process flow sheet for electrolysis.

average efficiency in generation and distribution of electric power from natural gas, the primary energy equivalent is approximately 1.3 Nm³ methane per 1 Nm³ H₂. Oxygen is a byproduct of electrolytic dissociation of water; with half the volume of H₂ oxygen is gained at the anode.

Steam reforming. The dominate steam-reforming processes convert natural gas, LPG or naphtha, with water vapor in the presence of a nickel catalyst, into a hydrogen-rich synthesis gas. The process reaction is:



at a temperature of 800°C–900°C and a typical pressure of 10–25 bar.

The classic steam-reforming process with external heat supply (Figs. 2 and 3) requires 0.46 Nm³ methane per Nm³ H₂. Steam is a process byproduct. After considering the additional energy requirement for electric drivers and the bonus of 73 Nm³ methane/ton of exported steam, the primary energy requirement is estimated at 0.40 Nm³ methane for each Nm³ of pure H₂.

New “low-temperature” steam-reforming processes can offer advantages for smaller H₂ users. The expense to import steam is compensated by lower feed and fuel consumption, and substantially reduces investment costs.

Methanol cracking. At significantly lower temperatures than in the steam-reforming process, the

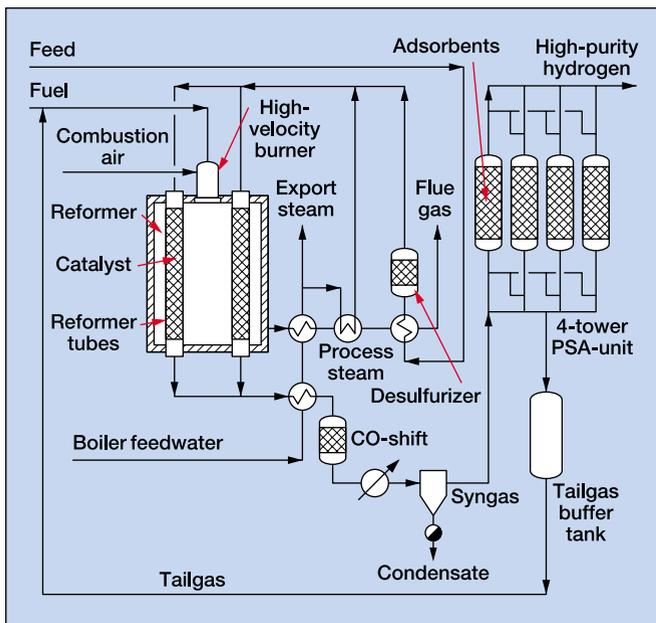


Fig. 2. Simplified process flow sheet for steam reforming.

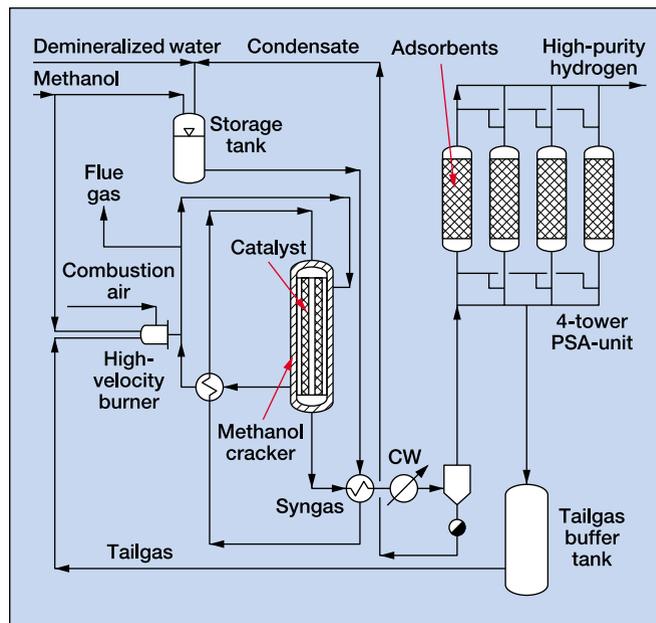


Fig. 4. Simplified process flow sheet for methanol cracking.

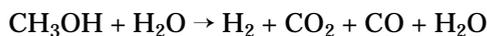


Fig. 3. Steam reformer with PSA.



Fig. 5. Methanol cracker with PSA.

methanol-cracking process splits methanol and steam in the presence of a copper-zinc catalyst (Figs. 4 and 5). The process reaction is:



at temperatures between 250°C–300°C and a typical pressure of 10–25 bar.

To produce 1 Nm³ of H₂, approximately 0.65 kg of methanol is required. Considering the energy requirement for electrical drivers and that 0.875 Nm³ methane is required to produce 1 kg methanol, the primary energy balance for the methanol-cracking process is 0.59 Nm³ methane per Nm³ pure H₂.

Hydrogen purification. The removal of O₂ and water vapor contaminates from hydrogen produced by electrolysis requires a catalytic DeOxo (to convert O₂ + 2H₂ → 2H₂O) and a dryer for the subsequent water vapor removal (Fig. 1). The catalytic reforming processes provide a syngas with approximately 75 vol% H₂ (dry basis) at elevated pressure. Pressure-swing adsorption (PSA) process can produce a purified H₂ with a typical purity of 99.999 vol%. In PSA, the nonhydrogen gases

of the syngas are adsorbed at the elevated pressure on activated carbon and molecular sieves. By expanding the adsorber vessel to almost atmospheric pressure, these nonhydrogen gases are desorbed and returned to the reformer as auxiliary fuel (Figs. 2 and 4).

CO₂ emissions. Isolating H₂ from water or hydrocarbons follows an endothermic reaction. For steam reforming and methanol cracking, burners provide the required energy. Consequently, these plants emit flue gas to atmosphere. Using electric power only, the water electrolysis process is free of CO₂ emissions at the site, but the corresponding emissions are relocated to the power generating facility as it processes electricity from fossil fuels. As an approximation, the specific CO₂ emissions can be related to these primary energy requirements:

Electrolysis	2.6 kg CO ₂ / Nm ³ H ₂
Steam reforming	0.8 kg CO ₂ / Nm ³ H ₂
Methanol cracking	1.2 kg CO ₂ / Nm ³ H ₂

Cost of investment. The various processes and operating conditions of electrolysis, steam reforming and methanol cracking have diverse investment costs,

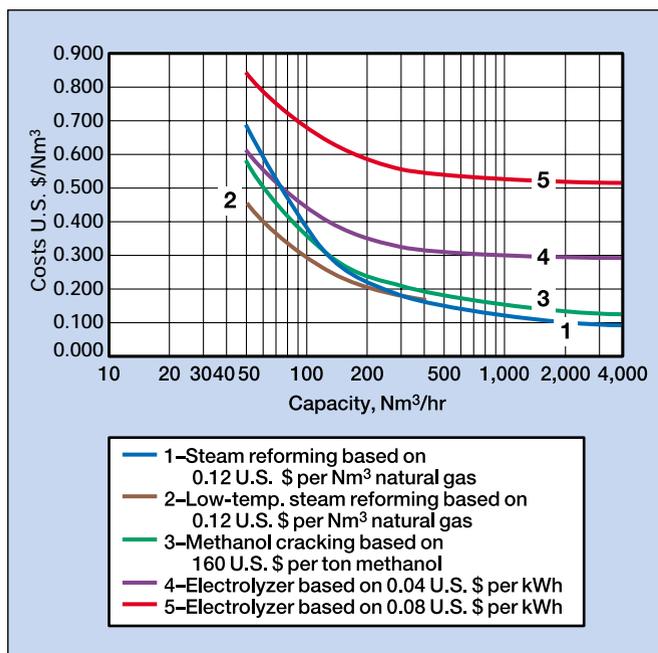


Fig. 6. Production costs per Nm³ H₂

whereby proportional costs vary with plant capacity. For plant capacities of 250 to 1,000 Nm³/h H₂ with a supply pressure of 16 bar g, Table 1 lists the relation of investment costs for the processes described.

Production costs. Fig. 6 lists the production costs for on-site H₂. These expenses include depreciation and interest on the capital investment, utilities, manpower and maintenance. Since market prices for natural gas and methanol vary considerably and depend on location and supply quantities, the production costs for hydrogen are shown for typical prices. If LPG or naphtha is used instead of natural gas in the steam-reforming process, 0.78 kg LPG or 0.84 kg naphtha may be set against 1 Nm³ methane. For the other processing utilities, the following costs were assumed for calculation purposes:

Electric energy	0.04 U.S.\$/kWh
Water, demineralized	1.10 U.S.\$/m ³
Water, cooling	0.07 U.S.\$/m ³

Apart from the costs for utilities and energy, these factors were taken into account in the calculation of the production costs:

Operating hours, annual	8,600
Annuity	depreciation of the investment costs over 10 years
Interest rate	6%
Maintenance	2.0% of the investment costs annually
Personnel	39,000 U.S.\$/man year

The typical energy requirement of 4.6 kWh/Nm³ H₂ by electrolysis results in the highest operating costs, thus, limits their share of total H₂ production to less than 1%. With decreasing plant capacity, however, the costs for utilities and energy become less significant,

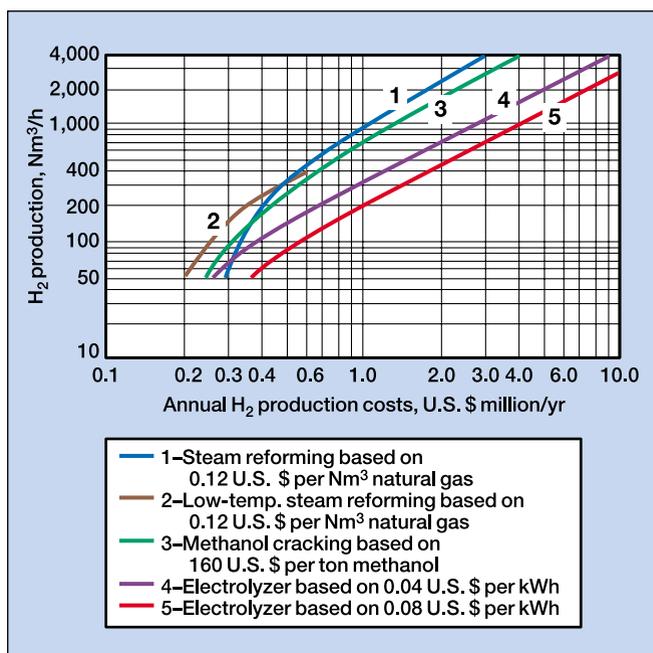


Fig. 7. Annual production costs of H₂.

Table 1: Cost of investment

Capacity	250 Nm ³ /h	1,000 Nm ³ /h
Steam reforming	100%	100%
Low-temp. steam reforming	71%	70%
Methanol cracking	79%	74%
Electrolysis	65%	154%

whereas the costs of depreciation and interest on the investment dominate.

The influence of annuity on the production costs for H₂ production also becomes clear when comparing high-temperature/low-temperature steam-reforming and methanol-cracking processes. Based on the price of 0.12 U.S.\$/Nm³ natural gas (NG) and 160 U.S.\$/ton methanol, the lower investment costs for low-temperature steam-reforming and methanol-cracking plants lower production costs for plant capacities up to approximately 300 Nm³/hH₂. The break-even point may shift substantially with changing utility costs, and must be calculated for each site-specific case.

Fig. 7 presents the total annual costs for on-site H₂ production for each process and the cost calculations. In only one year, the difference in production costs of the different processes can exceed total investment costs.

Purchasing hydrogen. An alternative to on-site production may be the purchase of H₂. The expenses, which have to be added to the production costs on the supplier's side, are frequently incurred for hydrogen purification, compression or liquefaction and transportation costs.

Also, the consumer must consider suppliers' general costs and profit. Typically, H₂ is supplied as a gas in high-pressure cylinders by truck or trailer. At a storage pressure of 200 bar, the transport volume is 5,560 Nm³ = 500 kg H₂ at a total transport weight of 40 tons.

For comparison, H₂ generated from a methanol supply at the same total transport weight is around 40,000 Nm³ = 3,600 kg H₂. The additional costs incurred by the

supplier for treatment, transportation and storage of H₂ at the consumer's facility are economical only in case of low or occasional requirements. Since the price varies considerably, depending on supply source and transport distance, a general market price for purchased hydrogen cannot be quoted. The decision between on-site production and purchasing of H₂ must be made by comparing the production costs shown in Figs. 6 and 7 and the most favorable offer obtained for the supply of H₂.



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