

Opportunities for an economical hydrogen supply

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Hydrogen is requisite for the hydrogenation of fats and oils. Depending on factors such as the hydrogenation process, mode of operation, and product quality, any one of the supply options discussed here could become the most economical solution for a particular case. Hydrogen can be acquired from different outside sources or from on-site generation using different processes. That various options exist allows a company to evaluate the most economical supply for a specific demand.

Hydrogen supply from outside by trailer

The economy of hydrogen supplied from off site is dominated by the cost of the transportation and will depend essentially on the distance between the source of H₂ and the end user. In general, purchasing hydrogen from outside is only desirable for occasional or low requirements. The costs may vary typically between U.S.\$0.30 and U.S.

\$0.50/Nm³. (Nm³ is the quantity of a gas that occupies one cubic meter at an absolute pressure of 101.325 kPa and a temperature of 273.15 K.)

Electrolysis

In the electrolysis process, water is split into hydrogen and oxygen by electric energy:



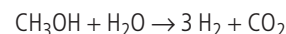
In this process hydrogen is obtained with a purity of approximately 99.9% by volume at atmospheric pressures. The oxygen and moisture contents of the hydrogen generated often require a DeOxo step to remove the oxygen and a dryer, in addition to a hydrogen compressor station, to make the hydrogen suitable for hydrogenation processes.

Electrolyzers are simple in operation and moderate in investment. However, with a typical consumption of 4.1 to 5.0 kWh per Nm³ H₂ generated, they are expensive to operate. Except for locations with extraor-

dinarily low-cost electricity, electrolyzers are only profitable for small hydrogen demands, typically up to 50 Nm³/h.

Methanol reforming

Methanol reforming splits methanol and steam into a synthesis gas under the presence of a copper–zinc based catalyst.



The process typically takes place at elevated pressures of up to 25 bar (2,500 kPa) and temperatures between 250 and 300°C. High-purity hydrogen is achieved by using a pressure-swing-adsorption (PSA) unit (Fig. 1). The main utilities for the process are methanol and demineralized water. For the production of 1 Nm³ H₂, approximately 0.65 kg methanol is required.

Methanol reformers are moderate in investment, complexity, and utility costs. They are preferably used at locations without access to natural gas and for typical capacity ranges of 50 to 3000 Nm³/h.

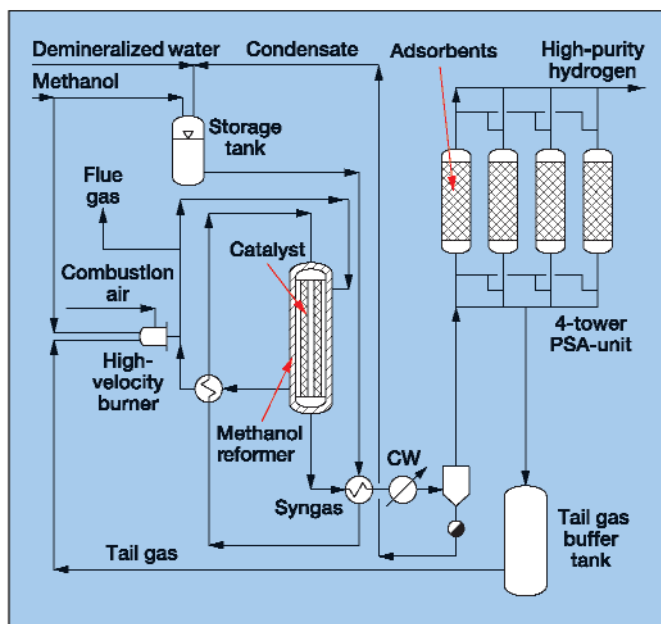


Figure 1. Simplified process flow sheet for methanol reforming.

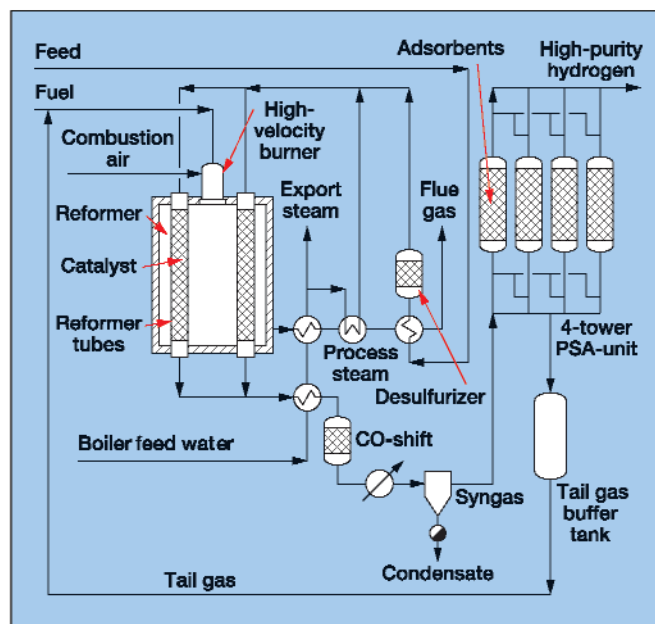


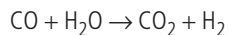
Figure 2. Simplified process flow sheet for steam reforming.



A methanol reformer with a pressure-swing-adsorption unit.

Steam reforming

With the steam reforming process (Fig. 2), hydrocarbons such as natural gas, LPG (liquefied petroleum gas, i.e., commercial propane and butane), or naphtha are mixed with steam and converted to a synthesis gas in the presence of a nickel catalyst. This conversion is an endothermic process.



Depending on the feed used, this reaction typically takes place at temperatures between 800 and 900°C and pressures of up to 30 bar (3,000 kPa).



A steam reformer with a pressure-swing-adsorption unit.

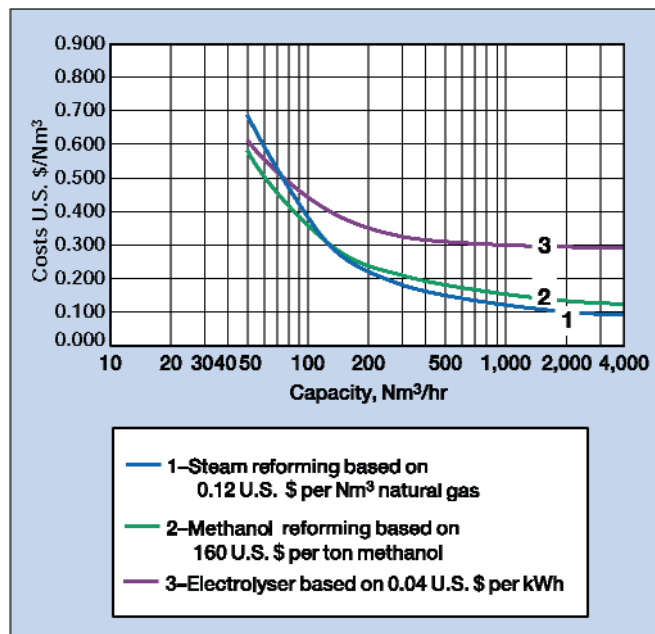
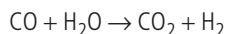


Figure 3. Production costs per Nm³ H₂.

In an additional catalytic process step, the hydrogen yield in the synthesis gas is increased by shifting the water-gas equilibrium to lower temperatures of about 400°C, using the surplus of water vapor remaining in the synthesis gas. This CO-shift reaction is an exothermic process.



The synthesis gas generated in this reac-

tion consists of the main components—H₂ and CO₂—and smaller amounts of CO, CH₄, and residual water vapor.

Upstream of the reforming step, a feed treatment unit is installed to remove sulfur components from the natural gas feed, which would otherwise poison the reforming catalyst. The steam required for the reforming process is generated by a waste heat boiler integrated into the process. The surplus steam can be exported and made available as a by-product. The export steam quantity is approximately 1 kg per Nm³ H₂ product. After the CO-shift reactor, the synthesis gas is cooled down to ambient temperatures and sent to the hydrogen purification unit. The purification step uses a PSA unit. In general, 0.45 Nm³ CH₄ per Nm³ H₂ generated is required for the steam reforming process.

Steam reforming is high in investment and low in utility costs. This process is typically used for production capacities from 200 to over 100,000 Nm³/h H₂.

Hydrogen purification

Both of the reforming processes generate a synthesis gas with a hydrogen content of approximately 75% by volume (dry basis) at elevated pressures. High-purity hydrogen, typically 99.999% by volume, is achieved by using a PSA unit. The remaining CO content in the hydrogen product is usually below 5 ppm by volume and can be reduced down to less than 1 ppm by volume.

For continuous operations, the PSA usu-

ally consists of four or five adsorbers/towers with several layers of different adsorbents. At any time, one adsorber is active for hydrogen production while the other three or four adsorbers are involved in different regeneration steps. When the adsorber has reached its adsorption capacity, it is taken out of hydrogen production and the synthesis gas is switched to a regenerated adsorber. The operation of the PSA unit is fully automatically controlled to achieve high efficiency. The typical hydrogen recovery from synthesis gas is about 80% in the case of a four-tower PSA unit and 85% for a PSA unit with five towers. In the case of load changes, the regeneration steps are automatically adjusted to the new operation conditions.

After the adsorption step, the adsorber is depressurized to a low pressure level to desorb the impurities from the adsorbents. The resulting tail gas is stored in the tail gas buffer tank. The buffer tank is needed to homogenize the fluctuations of quantity and heating value of the tail gas used for the burner as fuel gas.

Production costs

Figure 3 lists the production costs for the on-site generation of hydrogen. These expenses

cover depreciation and interest rate, utilities, personnel, and maintenance. Since market prices for natural gas and methanol depend on the location and quantity, the production costs for hydrogen are estimated for typical prices. If LPG or naphtha is used as feedstock instead of natural gas, 0.78 kg LPG or 0.84 kg naphtha may be equivalent to 1 Nm³ natural gas. Furthermore, the following costs were taken into account:

Electric energy:	U.S.\$0.04/kWh
Demineralized water:	U.S.\$1.10/m ³
Cooling water:	U.S.\$0.07/m ³

Apart from the costs for utilities and energy, the following additional cost factors were considered:

Annual operating hours:	8,600
Annuity:	10 years
Interest rate:	6%
Maintenance:	2% of investment per year
Personnel:	U.S.\$39,000/person year

The typical energy consumption by electrolysis of 4.6 kWh/Nm³ H₂ results in the highest operating costs. With decreasing plant capacity, however, the costs for utilities and energy become less significant, whereas the

costs of depreciation and interest rate on the investment dominate.

The influence of capital costs on production costs is obvious when comparing conventional steam reforming and methanol reforming. On the basis of the given utility prices, methanol reforming will have lower production costs for hydrogen capacities up to 150 Nm³/h. This break-even point may shift substantially with changing utility costs and annuity or interest rate and must be examined on a case-by-case basis.

For hydrogen requirements of approximately 200 Nm³/h and higher, the production costs using a conventional steam reforming process will be about U.S.\$0.20 down to U.S.\$0.10. For methanol reforming the production costs are slightly higher, but still significantly lower compared with the costs for a hydrogen supply from outside.

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