Industrial Scale Hydrogen Production from Biomass via CHOREN's Unique Carbo-V-process

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Industrial Scale Hydrogen Production from Biomass via CHOREN's Unique Carbo-V-process

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1 Introduction

Worldwide fossil-fuel demand is increasing rapidly and known resources are diminishing. Energy sources such as oil and gas in Western Europe are almost depleted resulting in an even higher dependency from fuel imports in the near future. These aspects combined with climate-change concerns have increased demand for renewable, clean and sustainable energy whereas "green" hydrogen as energy carrier could take a major role in the future.

Already 10 years ago, Germany-based CHOREN Industries, a leading gasification technology company, started development and testing of its highly innovative Carbo-V gasification process converting all kinds of woody biomass into high-quality synthesis gas. In 2009, CHOREN in collaboration with Shell finished construction work for its 120 m€ semi-industrial BTL (Biomass To Liquids) production plant in Freiberg, Saxony, being the first of its kind in the world. From mid 2010, the 18 million litres/year BTL facility will produce second-generation synthetic transport fuels from forest residues and waste wood. After successful commissioning and start-up of this demonstration facility, CHOREN will scale up its technology towards large scale Syngas production plants (Sigma plants).

2 The Carbo-V Gasification Process

The Carbo-V gasification process developed by CHOREN presents an innovative and efficient way of converting biomass feedstock into clean, tar-free and low-methane synthesis gas. Thereby the three-stage Carbo-V gasification process combines the advantages of an entrained flow gasification originating from coal utilization with an innovative pre-conditioning of the solid biomass which is done by a thermal process (pyrolysis) called "Low Temperature Gasification" (LTG).

In a <u>first process step</u> (LTG), the wood chips are thermally cracked at temperatures between 400 °C and 500 °C. The products of this pyrolysis decomposition are charcoal and a pyrolysis gas containing the volatiles components of the wood diluted in the gasification agent. The necessary heat for this pyrolysis process is gained by oxidizing a small amount of the charcoal in the LTG. This oxidation is performed by a gasification agent gas which consists of a mixture of oxygen and saturated steam. This mixture is fed to the LTG through nozzles at the bottom of the reactor.

The char from each LTG is cooled, de-compressed to atmospheric pressure, screened, grinded, stored and then fed to the High Temperature Gasifier.

In the <u>second process step</u>, the pyrolysis gas as well as the recycled residual coke is further oxidized with pure oxygen in the combustion chamber of the HTG at temperatures above the melting point of the fuel ash. Thus the hydrocarbon-rich pyrolysis gas will be converted to a hydrocarbon-free process gas consisting only of CO, CO_2, H_2 and steam.

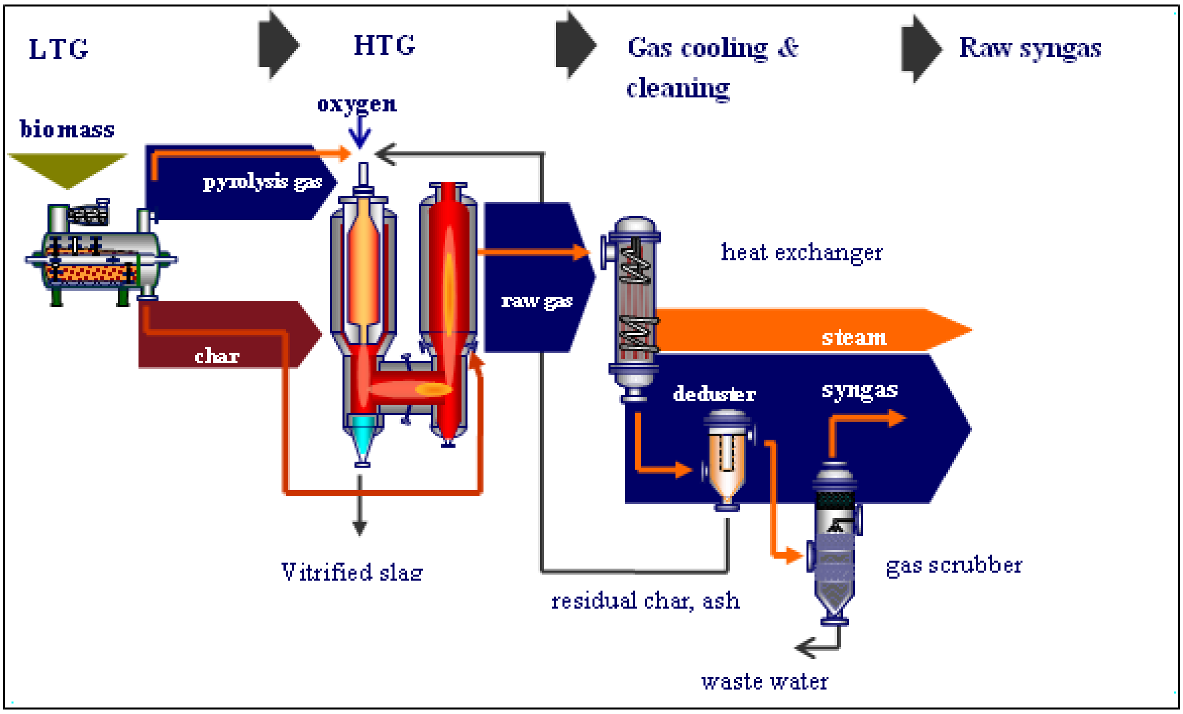

Figure 1: The Carbo-V gasification process.

In the third process step, char from the storage silo is fed to the endothermic part of the Carbo-V gasifier via a chamber sluice. The hot process gas from the burning chamber now reacts with the char in the gasification reactor of the HTG according to following basic reactions:

$C + CO_2 = 2\ CO$ $\Delta HR = +\ 172$ MJ/kmol

$C + H_2O = CO + H_2$ $\Delta HR = +\ 131$ MJ/kmol

As these reactions are strongly endothermic, the chemical reactions cool down the gas within the reaction vessel by more than 500 °C. This procedure is also called “chemical quenching” and is one of the major features of the Carbo-V gasification process. It allows keeping a high heating value of the product gas.

The crude syngas leaving the HTG is now further cooled down to below 200 °C via a special designed gas cooling system. The heat from the gas cooling system is used to produce high pressure steam (up to max. 90 bar).

Following the gas cooling system, the crude gas loaded with dust, residual carbon and the ash components of the feedstock has to be cleaned from solid particles. This occurs in a two-stage de-dusting system. The coarse particles are separated by a gas cyclone followed by a bag house filter system for the fine de-dusting. The residual coke is de-compressed over a chamber sluice and discharged from the system. After grinding of the residual coke to a suitable size, the solid fraction containing also the ash components is fed back to the burner of the high temperature gasifier by as a fluidized dense flow steam. A small portion of the filter dust is removed from the process to prevent the enrichment of impurities in the residual coke circuit.

Due to the high gasification temperature in the burning chamber of the HTG, the ash components get melted. The melted ash forms a solid layer on the refractory material within the burning chamber which protects the refractory material from thermal stresses thus permitting long life times of the refractory material. The melted ash trickles down at the wall of the gasifier and is collected in a water basin below the gasifier. In the water basin the melted ash is rapidly cooled and converted to a slag granulate. The vitrified slag will be periodically discharged from the gasifier over a chamber sluice.

In CHOREN's demonstration plant in Freiberg, also called the Beta plant, the next process step within the gasification island consists of a four (4)-stage wet gas cleaning system: gas cooling (by Venturi washer), chlorine removal, sulphur removal and finally gas cooling to below 40 °C.

3 CHOREN's Beta Plant in Freiberg

The Beta plant in Freiberg will serve as a first of a kind demonstration plant for the production of synthetic bio-fuels (BTL) featuring CHOREN's Carbo-V gasification technology and Shell's Fischer-Tropsch and refinery technologies. The plant has been designed for a yearly production capacity of 15,000 tons of BTL products (diesel and naphtha). The corresponding feedstock consumption will be appox. 65,000 tons/year of dry wood. Excess heat derived from the gasification as well as from the Fischer-Tropsch process will be converted to steam and subsequently converted to electric power by a steam turbine. The syngas is produced by a 45 MW oxygen-blown Carbo-V gasification unit which is operated with 5 bar pressure.

Figure 2: View on CHOREN's BTL demonstration plant in Freiberg (Beta plant).

Typically, the dry syngas composition consists of 35-40 vol.-% H_2 and 35-40 vol.-% CO. The balance is for CO_2 and little amounts of N_2 und CH_4.

Construction work of Beta plant was completed by mid 2009, followed by a comprehensive testing and approval period. In January 2010, hot commissioning of the gasification island has been started. The first operational results were rather encouraging especially regarding gas composition and gas quality. On the other hand, some mechanical problems and deficiencies within the process control systems have caused some delays which in terms are rather normal when commissioning new technologies.

Until summer 2010, the hot commissioning and testing procedure for the gasification island will be finished. After a short revision of the gasification plant, the syngas production will start again and the hot commissioning of the downstream units will follow. "First product" is scheduled by 3rd quarter, 2010.

4 Application Universe for Syngas

With the multi-stage Carbo-V gasification process a high quality synthesis gas (containing mostly CO and H_2) will be produced offering a wide spectrum of industrial applications. Besides the production of Fischer-Tropsch liquids (diesel, naphtha, jet kerosene) and waxes, the syngas may be converted to heat and power, to alcohols such as methanol or ethanol or to green hydrogen. Currently, CHOREN undertakes a feasibility study for the implementation of a gasification based commercial hydrogen production facility in South America using 100 % of woody biomass as fuel input.

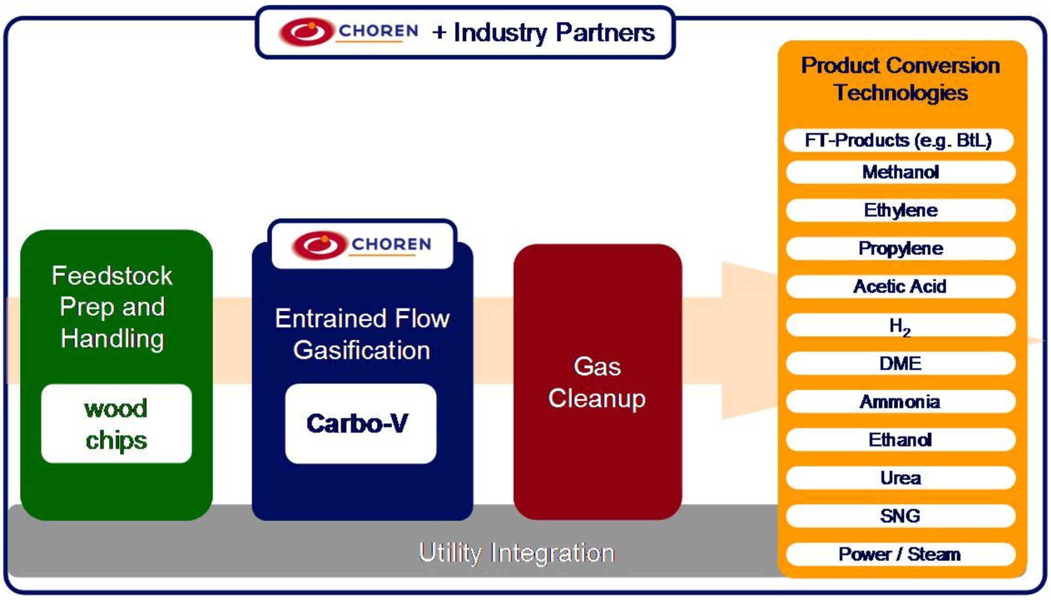

Figure 3: Application universe for syngas.

5 Large-scale Production of Hydrogen Derived from Biomass

Hydrogen does not exist alone in nature. Therefore, all hydrogen production processes are based on the separation of hydrogen from hydrogen-containing feedstock such as light hydrocarbons, water or bio-mass. Essentially, there are two methods to separate hydrogen: thermal and electro-chemical. The most common method to commercially produce hydrogen is based on the so-called Steam Methane Reformation Process using natural gas as feedstock. This process consists of two steps: 1) reformation of natural gas with high temperature steam to syngas and 2) using a water-gas shift reaction to form hydrogen and carbon dioxide from the carbon monoxide produced in the first step.

Steam Methane Reformation

Step 1: $CH_4 + H_2O \rightarrow CO + 3\,H_2$

Step 2: $CO + H_2O \rightarrow CO_2 + H_2$

To a lesser degree, hydrogen is produced by an Electrolysis process whereas water is divided into hydrogen and oxygen by passing electricity through an ionic water bath. Thereby, the production costs of hydrogen strongly depend on the costs of the electricity. In the case this electricity is generated by renewable technologies such as solar-, hydro- or wind power, hydrogen can be produced with almost zero greenhouse gas emissions. On the other hand, this production route is in most cases not attractive from an economic point of view.

The use of biomass as feedstock for hydrogen production has potential to combine the benefits of the electrolysis regarding environment with the benefits of the Steam Methane Reformation regarding productivity and economics. In principle, the gasification of biomass replaces the Steam Methane Reformer, whereas the subsequent downstream process will stay the same.

The overall process design of a biomass derived hydrogen production plant is illustrated in the following simplified block flow diagram.

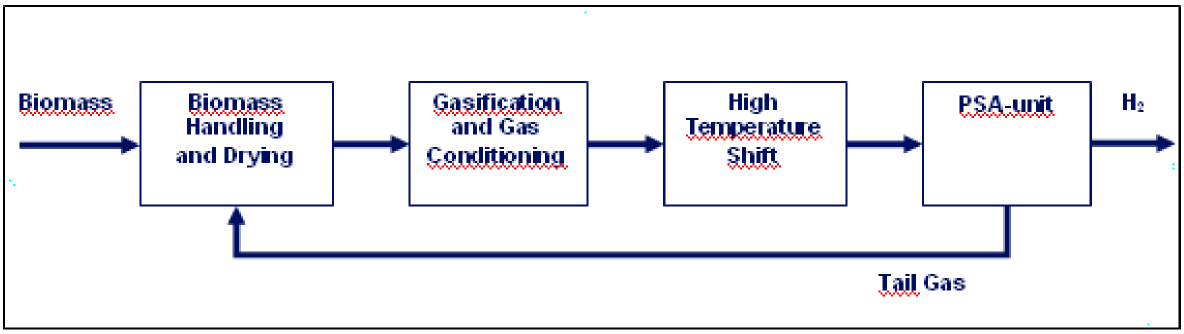

Figure 4: Hydrogen production via biomass gasification.

In a process study carried out by CHOREN, a 160 MW oxygen-blown and pressurized Carbo-V gasification unit has been selected to produce high quality syngas (CO plus H_2). Leaving the gasification unit, the syngas passes through a shift reactor where carbon monoxide reacts with steam to hydrogen and carbon dioxide. Leaving the shift reactor, the gas contains approx. 75 vol.-% hydrogen. The balance is for carbon dioxide and some unconverted carbon monoxide as well as very low amounts of methane and nitrogen. For the hydrogen purification, a pressure swing adsorption unit (PSA) is used to separate the hydrogen from the other gas components in the shifted gas stream. The PSA system adsorbs the CO, CO_2 and other impurities in a multi-stage fixed bed adsorber. The impurities desorb from the bed upon "swinging" the adsorber from the feed (high) to the tail gas (low) pressure and by using a high-purity hydrogen purge. A hydrogen recovery rate of up to 90 % is possible with a product purity of 99.999 vol. %. Beside the pure hydrogen product, the PSA system produces a low-pressure tail gas which contains also some hydrogen used for the regeneration of the adsorbent. This tail gas has a low heating value and can for example be used as fuel gas for the feedstock dryer.

With such a plant configuration, approx. 33,300 Nm^3/h respectively 3,000 kg/h of pure hydrogen can be produced using 32 tons/h of bone dry woody biomass. The production costs of the bio-hydrogen have been calculated with 60 to 90 Euros per MWh depending mainly on the variety of costs for biomass and electricity. The production cost of hydrogen via Steam Methane Reforming process usually is between 40 and 60 Euros per MWh based upon typical average market prices in Western Europe for natural gas.

6 Conclusion

From the results of our study work it can be concluded that green hydrogen (with low emissions) can be produced via biomass gasification economically in regions where natural gas prices are high or where cheap renewable electricity is not available. This applies all the more for regions where abundant biomass is available at low prices.