BIOMASS UTILIZATION FOR HYDROGEN PRODUCTION

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ABSTRACT

Renewable biomass and biomass-derived fuels could be readily gasified to produce a hydrogen-rich gas or hydrogen. Among the biomass energy conversion schemes gasification produces a product gas, which based on its properties could be used either to co-produce value-added byproducts or hydrogen. As a readily renewable fuel, biomass may become a significant component in the global sustainable energy mix as fossil fuel resources begin to deplete. In addition, biomass utilization can expedite mitigation of greenhouse gas emissions and carbon sequestration cycles and promote "green" industries with associated growth in rural economies. Hydrogen or hydrogen-rich gas produced from biomass could be readily used in most of the present natural gas or petroleum derived hydrogen energy conversion devices and also in advanced systems such as fuel cells. [1] For all hydrogen production processes, there is a need for significant improvement in plant efficiencies, for reduced capital costs and for better reliability and operating flexibility.

1 BIOMASS TO HYDROGEN CONVERSION

In biomass conversion processes, a hydrogen-containing gas is normally produced in a manner similar to the gasification of coal. However, no commercial plants exist to produce hydrogen from biomass.

Currently, the pathways followed are steam gasification (direct or indirect), entrained flow gasification, and more advanced concepts such as gasification in supercritical water, application of thermo-chemical cycles, or the conversion of intermediates (*e.g.* ethanol, bio-oil or torrified wood). None of the concepts have reached a demonstration phase for hydrogen production. [2]

Biomass gasification is an R&D area shared between H_2 production and biofuels production. Gasification and pyrolysis are considered the most promising medium-term technologies for the commercialisation of H_2 production from biomass. A typical flow sheet for the production of hydrogen from biomass is presented in Figure 1. [2] In terms of its energy requirements, the drying of biomass might not be justifiable; therefore, other pathways based on wet biomass are being sought as well.

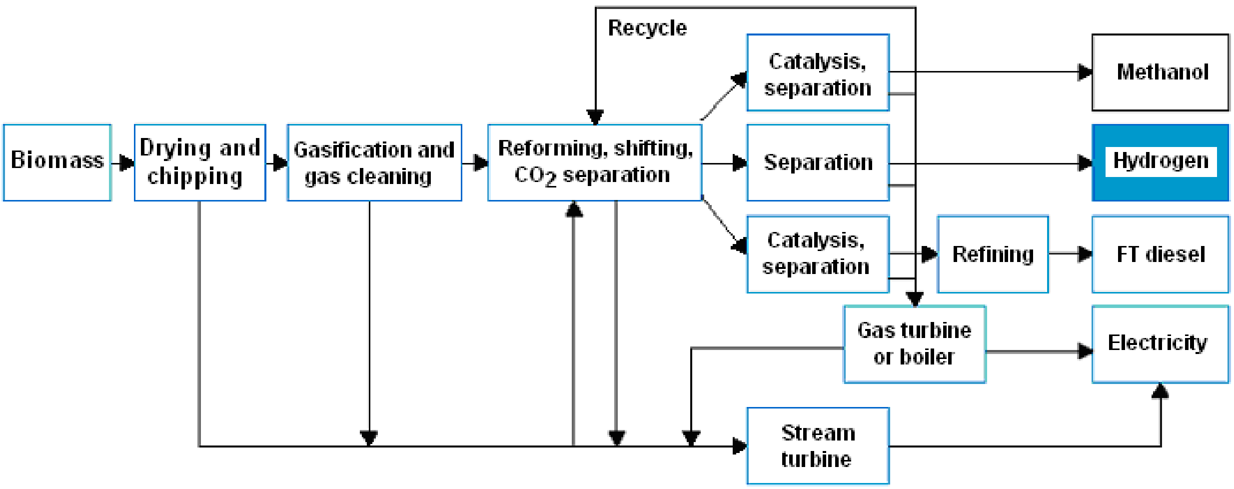

Figure 1 : Generic flow sheet for methanol, hydrogen or FT diesel production via biomass gasification [2]

Biomass feedstocks are unrefined products with inconsistent quality and poor quality control. The production methods vary according to crop type, location and climatic variations. Erratic fuels have contributed to the difficulties in technological innovation, since less homogenous and lowquality fuels need more sophisticated conversion systems. There is a need to rationalise the production and preparation of fuel to produce more consistent, higher-quality fuels that can be described by common standards. Large-scale systems tend to be suitable for cheaper and lower quality fuels, while smaller plants tend to require higher levels of fuel quality and better fuel homogeneity. A better understanding of this relationship, and the specific tolerances that each technology can accommodate, is needed. [2]

2 BIOMASS GASIFICATION FOR HYDROGEN PRODUCTION. PROCESS DESCRIPTIONS AND RESEARCH NEEDS

At present, there are no commercial biomass gasification processes for hydrogen production. In general, except for direct air-blown gasification, enriched-air or oxygen-blown gasification, steam gasification, or any other indirectly heated gasification process should be able to produce a synthesis gas, which could be converted to hydrogen. From the wide variety of biomass gasification processes that are being developed, processes considered to be suitable for hydrogen production are described in the following sections.

The following section highlight research needs for developing and commercializing biomass gasifiers for hydrogen production. The general issues relate to hydrogen handling. Compression, storage and transportation are not discussed.

2.1 Feed Preparation

Unlike fossil fuels, biomass is dispersed and lacks the infrastructure to ensure sustained supply of low-cost quality controlled gasification feedstock. Biomass has certain physical characteristics, such as low bulk density and its fibrous nature that presents many challenges in collection and transportation to a central gasification plant. [1]

Although, woody biomass feed preparation and feed handling systems are well developed for low-pressure systems, reliable feeders for many varieties of biomass for pressurized gasifiers are required. Lowcost pelletization of low-density herbaceous feed stocks would widen the range of renewable feed materials that are available for biomass gasification. [1] Pellets are easy and economical to transport and their relatively uniform shape and bulk density would render them easy to handle, store and feed pressurized systems.

2.2 Biomass Gasification

The present gasification systems are generally designed and operated to produce fuel gas for heat and power. The processes described in [1] also produce a fuel gas with little or no inert N_2, i.e., produce a synthesis gas containing primarily CO, H_2, CO_2, H_2O(g), and some gaseous hydrocarbons and condensable hydrocarbons. [1]

Fundamental research is needed to improve product selectivity, to produce essentially H_2, CO_2, and H_2O. The role of catalytic and non-catalytic bed additives on raw product gas yield and thermodynamic limitations should be investigated. Nearly total carbon conversion to produce such a raw gas containing H_2, CO_2, and H_2O would require minimal gas cleaning and separation to produce pure H_2. It is conceivable that direct H_2 could be increased by varying certain aspects of gasification reactor designs and operating conditions.

Gasification reactors should also be designed to incorporate the capability to thermally decompose organic condensates and ammonia that would be produced from systems employing conventional low-temperature gas cleaning and quenching.

Robust and sturdy low-cost, high-temperature heat transfer materials, which can operate up to 1100°C (~2000°F) would help develop indirect heating reactor designs that would prevent products of combustion from contaminating steam- or 'recycled product gas-' gasification of biomass.

Small-scale, low-cost air enrichment is another technology that will be beneficial to hydrogen production by biomass gasification. [1]

2.3 Raw Gas Handling and Clean-up

Significant progress has been made over the past 10 years towards developing a better understanding of biomass gas handling and conditioning processes and technologies for use in biomass gasification for advanced power production. However, there is need for further R&D in this process step for removal or elimination of particulates (from attrition of gasifier solids and secondary vapor-phase carbonaceous materials), alkali compounds, tar, chlorides, and ammonia. High-temperature gas processing, including reforming of hydrocarbons and water-gas shift to convert CO to H_2 should be investigated, particularly for raw product gases with all its contaminants produced in biomass gasification. In order to improve the overall thermal efficiency and to retain process simplicity, it is desirable to conduct these gas cleaning at raw gas temperatures or at temperatures which may require some gas cooling but does not require any reheating of raw cleaning gases.

Gas cleaning R&D should investigate CO_2 removal at high temperatures, although it may not be required for biomass gasifiers that may be developed for MCFC. Physical and ionic separation membranes that can separate H_2 at high temperatures would be useful to produce pure H_2, while CO or gaseous hydrocarbons are being chemically converted to H_2. [1]

Gas cleaning in general will have a major impact on the environmental impact of biomass gasifiers. Incomplete gas cleaning would shift the contaminant removal problem downstream from the gasifier, requiring expensive treatment of all process effluents.

2.4 Interface Issues and System Integration

As is the case with other energy conversion schemes, there could be several unique issues that need to be addressed for integrating hydrogen producing biomass gasification systems with selected end use applications. Obviously a central hydrogen producing biomass gasifier or gasifiers feeding to a central hydrogen storage and distribution system may face simpler problems compared to hydrogen producing biomass gasifiers that are closely coupled to selected chemical or energy conversion systems. [1]

2.5 System Definition and Market Assessment

Whenever, 'biomass gasification to hydrogen' becomes commercial, it would be necessary to determine the range of capacity of conceptual commercial plants. These specifications would be dependent to a great extent on the application, the cost and availability of feedstock. Upon defining the basic plant specifications, it would be possible to determine the process economics, their advantage over conventional alternatives, and hence the market potential for biomass gasifiers for specific applications. [1]

2.6 Information Dissemination and Policy

To promote the successful development and commercialization of biomass gasifiers for hydrogen production and utilization, timely dissemination of information is absolutely essential. Given the competition from conventional sources of hydrogen, public education and information are definitely required to craft, deploy, and implement policies that are conducive to commercializing hydrogen producing biomass gasification systems. It is crucial to document the performance of the new biomass gasification systems, to highlight success stories but also in showing solutions to problems that may arise. [1] The deployment of hydrogen producing biomass gasification systems for high-efficiency and selected value-added applications will benefit from policies that encourage the use of renewable fuels.

3. TECHNOLOGIES OF HYDROGEN PRODUCTION FROM BIOMASS

Hydrogen has the potential to be a clean alternative to the fossil fuels currently used in the transportation sector. This is especially true if the hydrogen is manufactured from renewable resources, primarily sunlight, wind, and biomass. Analyses have been conducted [3] to assess the economic feasibility of producing hydrogen from biomass via two thermochemical processes: 1) gasification followed by reforming of the syngas, and 2) fast pryolysis followed by reforming of the carbohydrate fraction of the bio-oil. [3]

The systems examined were gasification in the Battelle/FERCO low pressure indirectly-heated gasifier followed by steam reforming, gasification in the Institute of Gas Technology (IGT) high pressure direct-fired gasifier followed by steam reforming, and pyrolysis followed by coproduct separation and steam reforming. In each process, water-gas shift is used to convert the reformed gas into hydrogen, and pressure swing adsorption is used to purify the product. The delivered cost of hydrogen, as well as the plant gate hydrogen selling price, were determined. All analyses included Latin Hypercube sampling to obtain a detailed sensitivity analysis. [3]

3.1 Process Descriptions

Block flow diagrams of the three options for producing hydrogen from biomass are shown in Figure 2. Not shown on this diagram is the heat integration. The gasifier systems incorporated biomass drying and steam production with the process heat available. After meeting the process steam requirements, excess steam at 0.7MPa and 3.4 MPa (100 psi and 500 psi) was produced for export. [3] The same is true for the steam balance of the pyrolysis process. For all three systems, the base case assumes that the excess steam is sold to a nearby consumer.

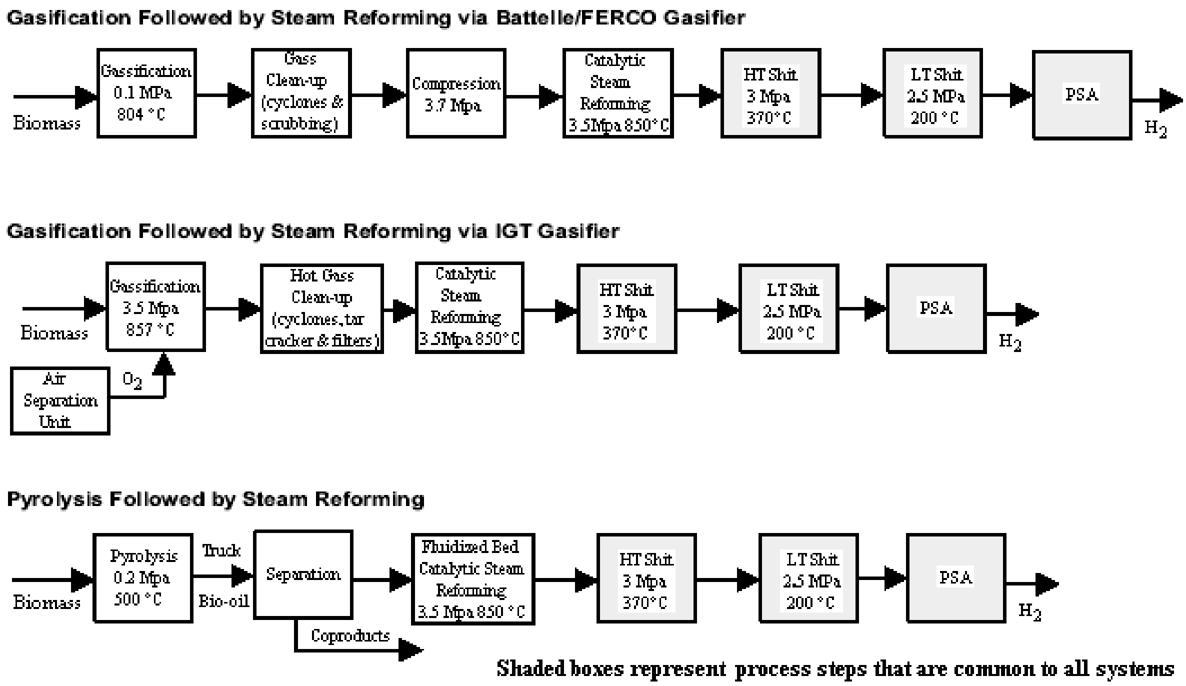

Figure 2: Systems Studied - Thermochemical Conversion of Biomass-to-Hydrogen [3]

One gasification option is based on a low pressure, indirectly-heated gasifier, like that developed at Battelle Columbus Laboratories (BCL) specifically for biomass gasification. [3] Future Energy Resources Corporation (FERCO) now owns the rights to this technology and is demonstrating it at the existing McNeil power plant in Burlington, Vermont. [3] This system is called indirectly-heated because the heat necessary for the endothermic gasification reactions is supplied by hot sand circulating between the char combustor and the gasification vessel. After clean-up, the syngas is cooled so that it can be compressed to the pressure required for the pressure swing adsorption (PSA) unit plus the expected pressure losses in the reactors. Following compression, the gasifier product gas is steam reformed and passed through two water-gas shift reactors to produce a gas concentrated in H_2 and CO_2. Finally, the hydrogen is purified in the PSA prior to storage and distribution. [3]

The second gasification system uses the IGT gasifier, which is a direct-fired high pressure gasifier. Much of the process scheme has steps similar to the Battelle/FERCO system. The major system components for the IGT hydrogen production process include biomass handling and drying, followed by gasification for which an air separation unit is required, hot gas clean-up, reforming, shift conversion, and hydrogen purification. [3]

The third technology studied in this analysis is fast pyrolysis of biomass followed by coproduct separation and steam reforming to produce hydrogen. Biomass is dried and then converted to an oil by very quick exposure to heated particles in a fluidized bed. [3] The char and gases produced are combusted to supply heat to the reactor, while the product oils are cooled and condensed. For this analysis, it was assumed that the bio-oil would be produced at several smaller plants which are closer to the sources of biomass, such that lower cost feedstocks can be obtained. The bio-oil is then shipped by truck from these locations to the hydrogen production facility. It is more economical to produce bio-oil at remote locations and then ship the oil, since the energy density of bio-oil is higher than biomass. Once the bio-oil arrives, a water extraction process separates the lignin-derived coproduct from the carbohydrate fraction of the oil. Hydrogen is produced from the carbohydrate fraction by steam reforming and shift conversion, followed by PSA for purification. The coproduct can be substituted for some of the phenol used to make phenol formaldehyde resins, used as wood adhesives. [3] The pyrolysis-based technology offers the opportunity for increased market potential and better economics as research on bio-oil continues.

3.2 Economical Aspects of Hydrogen Production from Biomass

Hydrogen can be produced economically from biomass. [3] The pyrolysis-based technology, in particular, because it has coproduct opportunities, has the most favorable economics. However, the gasification processes also produce hydrogen for less than many other renewable technologies. An added benefit of biomass as a renewable feedstock is that it is not intermittent, but can be used to produce hydrogen when needed. [3] Uncertainties exist, however, and must be addressed through increased research and validation projects. With scientific and engineering advancements, biomass can be viewed as a key economically viable component to a renewably-based hydrogen economy.

It is important to continue using risk assessment for analysis in the Hydrogen Program because this technique accounts for uncertainties in the assumptions. As shown in [3], the mean hydrogen selling price as determined from Crystal Ball® was higher than the predicted price calculated in the Excel® cash flow spreadsheets. In future studies, a combination of uncertainties could result in a large difference between predicted and mean values. [3] This stochastic modeling method pinpoints areas with the greatest contribution to variance, thus showing areas requiring additional research.

4 Conclusion

Hydrogen can be produced from a variety of feedstocks [2]. These include fossil resources, such as natural gas and coal, as well as renewable resources, such as biomass and water with input from renewable energy sources (e.g. sunlight, wind, wave or hydro-power). A variety of process technologies can be used, including chemical, biological, electrolytic, photolytic and thermo-chemical [2]. Each technology is in a different stage of development, and each offers unique opportunities, benefits and challenges. Local availability of feedstock, the maturity of the technology, market applications and demand, policy issues, and costs will all influence the choice and timing of the various options for hydrogen production. Hydrogen has the potential to be a clean alternative to the fossil fuels. Gasification and pyrolysis are the most promising medium-term technologies for the production of H_2 from biomass.

5 REFERENCES

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