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## Biomass Gasification for Hydrogen Production – Process Description and Research Needs

This Technology Report from Task 33 was prepared by the Task Leader Suresh Babu for ExCo56 in Dublin in October 2005.

### Introduction

Renewable biomass and biomass-derived fuels could be readily gasified to produce high purity hydrogen or hydrogen-rich gas. Among the biomass energy conversion schemes, gasification produces a product gas, which could be used either to produce hydrogen or co-produce value-added by-products. As a readily renewable fuel, biomass may become a significant component in the global sustainable energy mix if the use of fossil fuels is limited for any number of reasons. In addition, biomass utilisation can expedite mitigation of greenhouse gas emissions and promote introduction of '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 systems and also in advanced power generation devices such as fuel cells.

### Process Descriptions

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 producing either hydrogen or hydrogen-rich gases are described in the following sections.

***BIOSYN Gasification and Gas Conditioning Technologies:*** The BIOSYN gasification process [1] (Figure 1) was developed during the 1980s by BIOSYN Inc., a subsidiary of Nouveler Inc., a division of Hydro-Quebec (Montréal, Quebec, Canada). The process is based on a bubbling fluidised bed gasifier containing a bed of silica or alumina capable of operating up to 1.6 MPa. Extensive oxygen-blown biomass gasification tests were conducted during 1984 to 1988, in a 10 tonnes/hour (t/h) demonstration plant located at St-Juste de Bretennières, Québec, Canada, to produce synthesis gas for methanol production. Air blown atmospheric gasification tests were also conducted for evaluating cogeneration. In the following years, a 50 kg/h BIOSYN process development unit has also proven the feasibility of gasifying primary sludges, RDF, rubber residues (containing 5 - 15% Kevlar), and granulated polyethylene and propylene residues to produce hydrogen-rich synthesis gases.

The process accepts feed particle sizes up to 5 cm, feed bulk densities higher than 0.2 kg/l and feed moisture content up to 20%. The thermal efficiency for biomass gasification varies from 70 to 80%. The product gas containing mostly CO, CO<sub>2</sub>, and H<sub>2</sub> could be cleaned to remove carry over dust and condensable tar and upgraded to produce high-purity hydrogen. With air as the gasifying agent the HHV of the fuel gas is about 6 MJ/Nm<sup>3</sup>. Enriched air, with

40% oxygen, can produce a fuel gas having a higher heating value (HHV) of about 12 MJ/Nm<sup>3</sup> at half the gas yield. The raw gas cyclones remove 85 to 95% of entrained particles.

The BIOSYN Options for Waste & Biomass Gassification & Synthetic Gas Conditioning

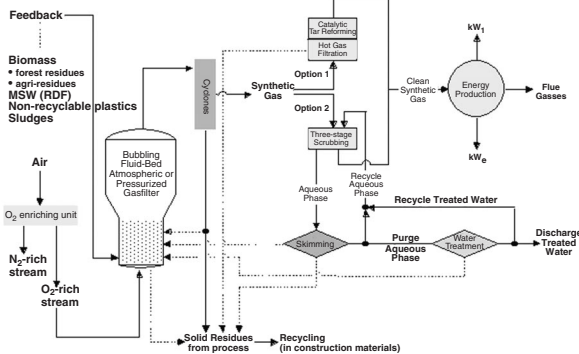


Figure 1: BIOSYN Process

The supporting R&D conducted during the demonstration of the BIOSYN Process, includes gas scrubbing for efficient tar removal with reduced water requirements, recycling the insoluble tars to the gasifier, wet oxidation and adsorption of dissolved organic compounds in the scrubbing water, and recycling carbon-rich ashes and carry over carbon with adsorbed organic compounds to the gasifier. The R&D effort also included hot-gas filtration of entrained dust using a static bed of perlite particles and a moving sand bed filter, and catalytic steam cracking of tar. Proprietary gas clean-up catalysts were developed to decompose 99% of tars and 97% of naphthalene compounds. The fully integrated BIOSYN Process, with hot-gas filtration and high-temperature tar reforming, water-gas shift conversion to convert CO to hydrogen and CO<sub>2</sub>, and CO<sub>2</sub> removal to produce high-purity hydrogen, was never demonstrated. The BIOSYN Process is now commercialised by Enerkem Technologies Inc, a subsidiary of the Kemestrie Group, a spin-off company of the University of Sherbrooke. Recently, a commercial installation to gasify 2.2 t/h of granulated polypropylene residues was planned for construction in Spain. Environmental International Engineering S.L., a Spanish-based development and

engineering group, in partnership with Enerkem, was planning to erect and commission the plant. The electricity output of the plant will be sold to the grid.

**FERCO SilvaGas Process:** The FERCO SilvaGas Process [2] (Figure 2) employs the low-pressure Battelle (Columbus) gasification process which consists of two physically separate reactors; a gasification reactor in which the biomass is converted into a medium calorific value (MCV) gas and residual char at a temperature of 850 to 1000°C, and a combustor that burns the residual char to provide heat for gasification. Heat transfer between reactors is accomplished by circulating sand between the gasifier and combustor. Since the gasification reactions are supported by indirect heating, the primary product is a synthesis gas with medium calorific value. A typical product gas composition obtained in pilot plant tests, at steam to biomass (wood chips) ratio of 0.45, is 21.2% H<sub>2</sub>, 43.2% CO, 13.5% CO<sub>2</sub>, 15.8% CH<sub>4</sub>, and 5.5% C<sub>2</sub>+. The estimated HHV of this fuel gas is 17.75 MJ/Nm<sup>3</sup>. A 200 tonnes/day (t/d) capacity Battelle demonstration gasification plant was built at the McNeil Power plant in Burlington, Vermont. Following plant shakedown and initial tests the plant has operated intermittently. At this plant, the fuel gas was co-fired in the existing McNeil wood fired boiler. The process was developed by US DOE Biomass Power Program, FERCO, Battelle Columbus Laboratory, Burlington Electric Department, Zurn Industries, OEC/Zurn, and NREL.

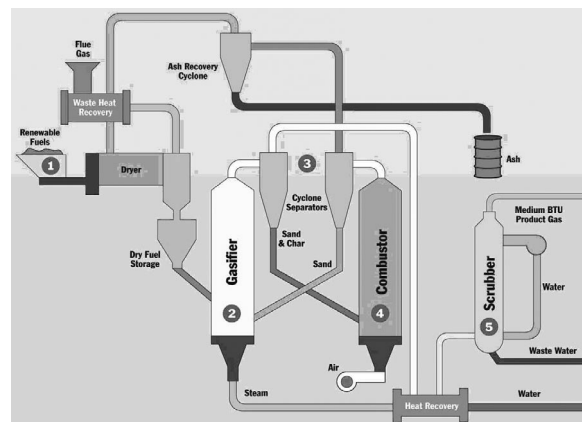


Figure 2: SilvaGas Process

**MTCI Process:** The MTCI gasification process (Figure 3) also employs indirect heating to promote steam gasification of biomass to produce a MCV fuel gas. The gasifier combusts part of the fuel gas in pulsed combustion burners which promote heat transfer to the gasification section. Extensive pilot plant tests were conducted in a 20 t/d process development unit (PDU) at the MTCI laboratories near Baltimore, Maryland. These tests also included evaluation of black liquor gasification process. Based on the PDU tests a 50 t/d capacity black liquor gasification demonstration unit was built at Weyerhaeuser's New Bern facility.

In the MTCI Process, the black liquor is steam reformed/gasified at an operating temperature of about 600°C (~1,110°F). The raw gas is upgraded through several steps of gas cleanup, resulting in a synthesis gas rich in hydrogen (>65% by volume) with a higher heating value (HHV) of approximately 10.4 MJ/(dry)Nm<sup>3</sup>. In one of the pilot test campaigns, cleaned synthesis gas was metered to a solid-oxide fuel cell operating at about 1000°C (1830°F), which produced a net 2.6 volts D.C., 62 amps or an equivalent of 161 watts of electricity.

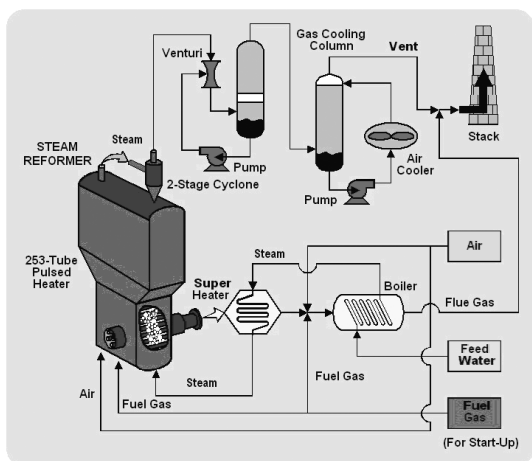


Figure 3: MTCI Process

The first MTCI black liquor gasification plant was commissioned in September 2003, at the Norampac mill in Trenton, Ontario, Canada. The plant was designed to handle 115 t/d black liquor (60% solids). The gasifier has operated for extended periods, but has experienced some bed agglomeration problems. The second MTCI plant, with a capacity of 200 t/d sodium carbonate black liquor (with 60% solids), was launched in 2001 by Georgia Pacific, Fluor Daniels, and Stone Chem, with support from USDOE. The five-year demonstration project is located at the Georgia Pacific paper mill in Big Island, Virginia. The project will cost approximately \$87 million with about 50% cost contribution from industry. Plant commissioning was started in the fall of 2004, and to date the unit has operated at 50% of design capacity. No agglomeration problems were observed at this demonstration plant.

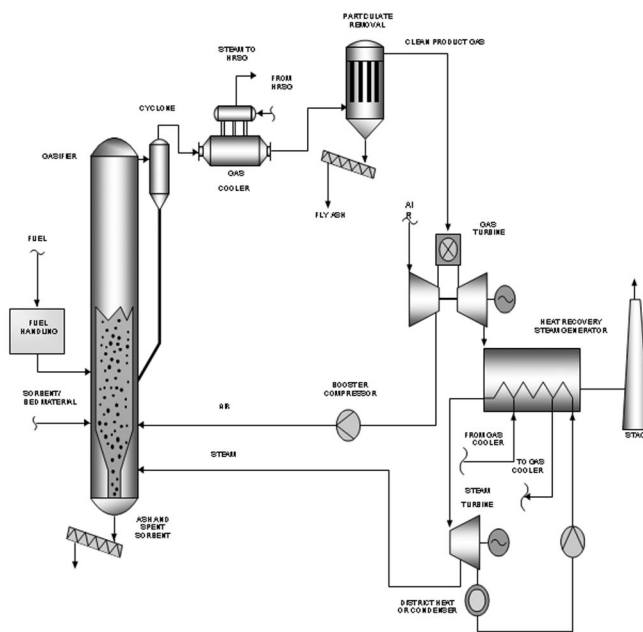


Figure 4: RENUGAS Process

**RENUGAS Process:** The GTI/IGT RENUGAS®, Process [4] (Figure 4) employs a 20 bar pressurised bubbling fluidised bed. The process was extensively

tested with a variety of biomass materials, including bark-paper sludge mixtures, bagasse, and pelletised alfalfa stems in a 12 t/d PDU at IGT test facilities in Chicago. Subsequently USDOE selected the RENUGAS Process for scale-up and demonstration, using bagasse, at the HC&S sugar mill at Paia in Hawaii. The project was terminated when the 100 t/d demonstration plant had limited success in handling the low-density, shredded bagasse. A typical gas composition obtained in the IGT PDU with bagasse at 2.2 MPa, and 850°C is 19% H<sub>2</sub>, 26% CO, 37% CO<sub>2</sub>, 17% CH<sub>4</sub>, and 1% C<sub>2</sub>+. The heating value of this fuel gas is approximately 13 MJ/Nm<sup>3</sup>. The project participants included US DOE Biomass Power Program, IGT, Westinghouse Electric Corporation, State of Hawaii, PICHTR, and HC&S.

Although, the pressurised air-blown RENUGAS process was initially developed for IGCC applications, by replacing air with oxygen, the process could produce synthesis gas that could be upgraded to high-purity hydrogen.

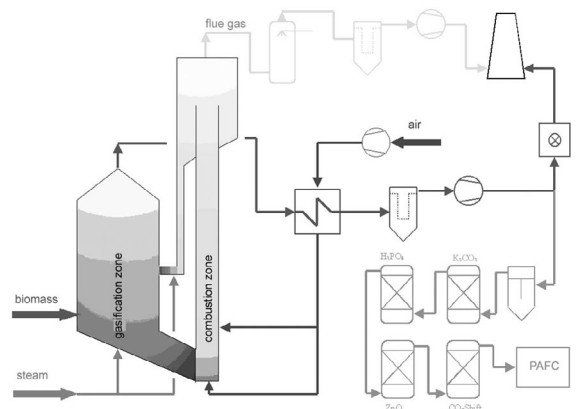
Carbona, which licensed the Renugas technology from GTI, has constructed and tested a 15 MWth high-pressure (20 bar) Renugas pilot plant in Tampere, Finland [5]. Around 1993, Carbona successfully operated the pressurised gasifier for over 2000 hours with a variety of biomass wastes and has also evaluated hot-gas filtration for IGCC application. In October 2004, Carbona reported that ground has been broken for building a 5.4 MWe capacity low pressure, Renugas demonstration project in Skive, Denmark. The project will start its operation with pelletised wood.

In January 2005, GTI completed the shakedown of a new 24 t/d, adiabatic Flex Fuel Test Facility in Des Plaines, Illinois [5]. This facility is capable of gasifying up to 30 t/d of biomass and at operating pressures up to 25 bar.

**Forced Internal Circulation Fluidised Bed (FICFB) Process:** The two-stage, combined fluidised bed gasifier and CFB combustion process developed by the Technical University of Vienna (TUV), Austria (Figure 5) with Repotec has

demonstrated exceptional rapidity of success in scaling-up the laboratory scale unit to a commercial demonstration plant Güssing, Burgenland [6]. The principal novelty of the process is its ability to produce a MCV fuel gas without the use of oxygen. The process employs a catalytically active circulating fluidised bed of solids that can reduce tar in the raw gases. The raw product gases are cooled for heat recovery and scrubbed with an organic liquid to remove most of the tar. The raw MCV product gas can be processed to produce hydrogen or hydrogen-rich gas. The condensate along with some of the scrubber solvent is recycled to the combustion zone for complete thermal decomposition of all condensable organic compounds produced during biomass gasification. The clean gas is then introduced to an Jenbacher gas engine to generate a gross ~2.0 MWe power and ~4.5 MWth heat. The reported parasitic power consumption is ~0.2 MWe. The electrical efficiency of the Jenbacher gas engine is 36 to 37%. At the end of 2004, the gasifier had logged more than 14,000 hours and the total operating time with the integrated gasifier and gas engine was about 11,000 hours.

A typical dry, raw gas composition reported from air-blown biomass gasification tests is given below in % by volume: H<sub>2</sub>= 30-45, CO= 20-30, CO<sub>2</sub>= 15-25, CH<sub>4</sub> = 8-12 vol.%, N<sub>2</sub>=1-5, (NH<sub>3</sub>= 500-1000 ppm, H<sub>2</sub>S = 20-50 ppm, Tar= 0.5-1.5 g/Nm<sup>3</sup>, Particles= 10-20 g/Nm<sup>3</sup>).

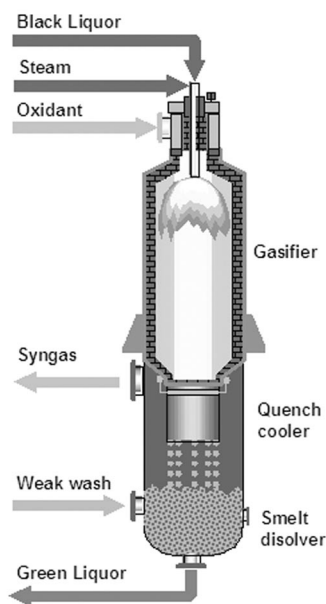


**Figure 5:** FICFB Gasification Process

**CHEMREC Process:** In 1987, the development of the Chemrec Process (Figure 6) for black liquor gasification was started in Sweden [7,8]. The process was bought by Kvaerner in 1990. In 2000 Kvaerner sold their majority rights to the German industrial group Babcock Borsig Power (52%) and to the Swedish company Nykomb Synergetics (24%). Since 2002, Chemrec has been in search of seeking new industrial partners because Babcock Borsig Power is in insolvency and its part in Chemrec has been bought by Nykomb Synergetics.

The Chemrec process can be operated at slightly above atmospheric pressure for incremental black liquor gasification in parallel with an existing recovery boiler. The process when operated under pressurised system can replace the recovery boiler. The pressurised black liquor gasification combined cycle mode (BLGCC) is more energy efficient than the recovery boiler and can generate approximately double the amount of electric power than a modern recovery boiler. The Chemrec gasification reactor is similar to the Texaco gasifier (now owned by GE). Black liquor is injected with oxygen, into a high-pressure (~30 bar) and high temperature (~950°C) reactor to gasify the cellulose, lignin components and smelt and reduce the inorganic salts. The favourable reaction kinetics in the gasifier due to the presence of a catalyst (Na and K) results in low methane content gas compared to normal gasification of biomass. In the low-pressure Chemrec process, black liquor is gasified with air. Atomisation and droplet size are very important to gasifier performance; atomisation is achieved using medium pressure steam. The high-pressure Chemrec process is operated with oxygen. The black liquor injection nozzles are designed to facilitate on-line cleaning. The reactor temperature is maintained at about 950°C in the lower part of the gasifier. An oil or gas fired burner at the top of gasifier is used to heat the gasifier for start-up and for hot stand-by. The chemical smelt is recovered from the gas stream at the base of the gasifier by quenching with condensate. The product green liquor is pumped to the mill system. A small quantity (a few percent) of sulphur, as H<sub>2</sub>S, leaves with the product gas in the

low-pressure system while approx 60% of sulphur leaves with the product gas in the high-pressure system. In the pressurised system, the H<sub>2</sub>S is removed by scrubbing employing standard H<sub>2</sub>S/COS removal technology. By proper selection of the desulphurisation scrubbing process, the absorption of CO<sub>2</sub> can be reduced. With air gasification, the product is an LCV gas, while pressurised oxygen blown gasification results in a MCV gas.



**Figure 6:** The Chemrec Process

Chemrec has provided the following data on gasifier performance, for the low and high pressure (30 bar) gasification cases. The gas compositions are from two slightly different black liquor feed stocks.

The Swedish Government is providing \$25 million (50% matching funds) to develop and verify the performance of the Chemrec pressurised process in two steps. Chemrec has constructed a 20 t/d dry solids (3 MWth), oxygen-blown development plant in Piteå, Sweden. After about one year of testing the process will be scaled up to a 300 t/d dry solids capacity and built as a complete BLGCC plant. The Kappa

**Table 1:** Gasifier Performance Predictions for Operation with Air and Oxygen

	Low Pressure Air Blown	High Pressure Oxygen-blown
<b>Assumptions:</b>		
Reactor Temp, °C	950	950
Reactor Pressure, bar	2	30
Air feed, t/tds	2.2	
O <sub>2</sub> feed, t/tds	—	0.34
Oxidant temp, °C	100	135
<b>Gas Composition (vol. %):</b>		
CH <sub>4</sub>	0.2	1.1
CO	6.0	29.5
CO <sub>2</sub>	12.5	14.6
COS	-	0.04
H <sub>2</sub>	8.6	31.1
H <sub>2</sub> O	26.3	22.2
H <sub>2</sub> S	0.2	1.5
NH <sub>3</sub>	0.01	0.00
N <sub>2</sub> + Ar	46.2	0.18
<b>Higher heating value:</b>		
(MJ/m <sup>3</sup> , dry, at 15°C)	2.6	10

Typical black liquor properties are: C 37.2%, H 3.6%, O 34.4%, S 3.7%, N 0, Na 18.6%, K 2.5%, HHV: 14.36 MJ/kg, dry

Kraftliner mill in Piteå has expressed a desire to provide the host site for the plant. This effort, which began in 2001, will continue through 2006. Upon successful operation in the 20 t/d development plant, US pulp and paper industry and US DOE may consider building a commercial BLGCC demonstration based on the Chemrec technology in USA .

As shown, the gas composition from the pressurised Chemrec process is well suited for further treatment to produce synthesis gas which then can be converted into automotive fuels such as methanol, DME, FTD or hydrogen.

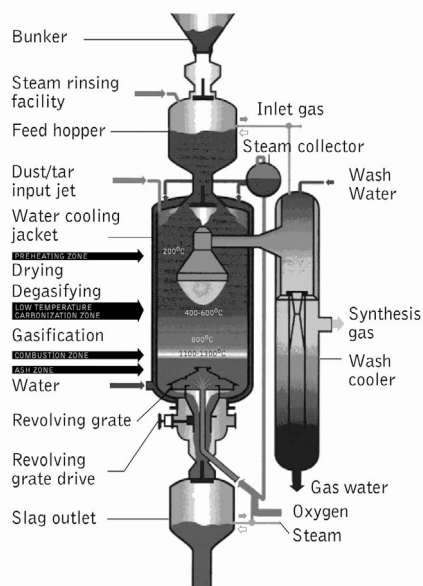
The operation of a 300 t/d dry solids capacity, low-pressure Chemrec gasifier in New Bern (Weyerhaeuser Mill) was started in 1996 and stopped in January 2000 when a crack was detected in the reactor vessel. The plant was taken out of operation and extensive investigations were carried out to understand and come up with a new design to avoid further structural problems. The plant construction was modified and the Weyerhaeuser gasifier has resumed operation in 2003. The new gasifier refractory is expected to last for about two years while the previous lining operated satisfactorily for a little over one year.

**SVZ Schwarze Pumpe GmbH:** SVZ [9] has converted some of the existing former East German era, FDV Process coal gasifiers in Schwarze Pumpe, Germany to convert biomass, coals, and wastes into clean fuel gas and synthesis gas (Figures 7a, 7b, 7c). The plant gasifies a wide variety of waste materials along with low-rank coals in an updraft moving bed gasifier. The waste materials include demolition wood, used plastics, sewage sludge, auto-fluff MSW, contaminated waste oil, paint and varnish sludge, mixed solvents, tars, and on-site process waste streams. The waste materials are blended with coal at a ratio of 4:1. SVZ has developed an effective feed handling system which employs thermal pre-treatment to convert heterogeneous feed materials to produce a nearly uniform in shape and bulk density gasifier feedstock.

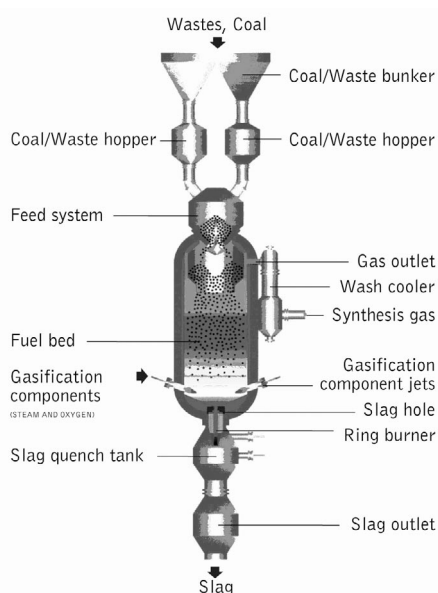
The oxygen-blown, 25 bar-pressurised, 14 t/h FDV process, similar to Lurgi’s moving bed coal gasification process, converts the mixed feedstocks to MCV fuel gas or synthesis gas. The raw gas is subjected to conventional (Rectisol) gas cleaning to separate contaminants from the product gas.

The SVZ facility has also built a 25 bar pressurised, 35 t/h capacity British Gas Slagging Lurgi gasification system for converting mixed feed stocks to MCV fuel gas or synthesis gas. As is the case with the FDV Process, the raw gas is subjected to conventional gas cleaning to produce a clean product gas and liquid and solids containing waste slurry stream.

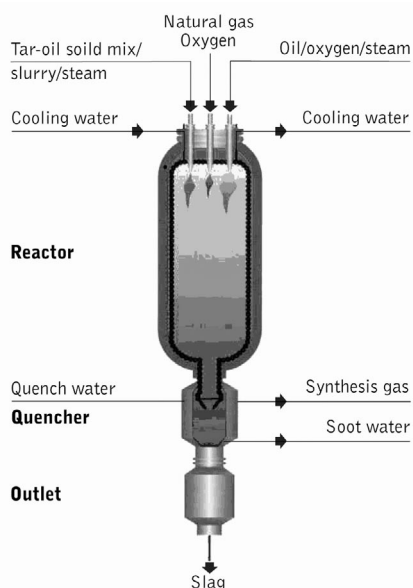
The third oxygen-blown, refractory lined gasifier is the FSV 15 t/h entrained flow gasifier, similar to the TEXACO process, which serves the role of a ‘bottoming’ gasifier that effectively treats the hydrocarbons containing waste streams from gas processing into a contaminant-free synthesis gas and mineral slag. If required, a supplementary fuel, i.e. natural gas is used to maintain the reactor temperature in the range of 1600 to 1800°C. This process is today owned by Lurgi and called the Multi Purpose Gasifier.



**Figure 7A:** Pressurised Moving Bed Gasifier with Revolving Grate



**Figure 7B:** Pressurised Moving Bed Gasifier with Liquid Slag Discharge



**Figure 7C:** SVZ Schwarze Pumpe Entrained Flow Gasifier with Slag Discharge

The SVZ plant is a first-of-a-kind integrated gasification, methanol and combined-cycle electricity production plant that converts contaminated and difficult to handle waste materials to clean, value-added products. The high gasification temperatures of up to 1800°C are high enough to totally decompose contaminants in the product gas or gas scrubbing effluent streams. The vitrified slag, the only gasifier waste product, safely encapsulates any residual pollutants and can be used as construction material.

In July 2002, SVZ was sold to ORESTO, a subsidiary of Nord GB Gesellschaft für Beteiligungen mbH, Hamburg.

**CHRISGAS Project:** Between 1993 and 1999, Sydkraft Ab adopted the Ahlstrom/FW CFB gasification process to develop and demonstrate the first pressurised Bioflow biomass gasification IGCC process for CHP (9 MWth and 6 MWe) application in Värnamo, Sweden [7]. This demonstration, widely

recognised for its technical success, operated the pressurised CFB gasifier for about 8500 hours. The integrated operation of the pressurised gasifier with hot-gas clean-up and power generation in a close-coupled Alstom's (now part of Siemens) Typhoon gas turbine was demonstrated for over 3600 hours. Although, the facility has been mothballed for several years, it will be reactivated as the centre piece for demonstrating the CHRISGAS project, a multi-national consortia technology development effort. The project's mission is to develop pressurised, oxygen-blown gasification of biomass and wastes to produce synthesis gas and its subsequent conversion to transportation liquid fuels.<sup>9</sup> The results from the CHRISGAS project should be also useful for evaluating the production of hydrogen from biomass.

The CHRISGAS project is coordinated by Växjö University at the Växjö Värnamo Biomass Gasification Centre (VVBGC). The Project team includes, AGA-Linde, Catator, KS Ducente, Royal Institute of Technology (KTH), S.E.P. Scandinavian Energy Project, TPS Termiska Processor, (Valutec), Växjö Energi, TK Energi, DK, Valutec, FI, FZ Jülich, DE, Linde, Pall Schumacher, University of Bologna, IT, Technical University Delft, NL, and CIEMAT, ES. The project budget is more than Euro18 million.

### Research Needs

The following sections highlight research needs for developing and commercialising biomass gasifiers for hydrogen production.

### 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. Although the feed preparation and feed handling systems for woody biomass are well developed for low-pressure

systems, reliable feeders for other types of biomass for pressurised gasifiers require further development.

Low-cost pelletisation of low-density herbaceous feedstocks would widen the range of renewable feed materials that are available for biomass gasification. Pellets are easy and economical to transport and their relatively uniform shape and bulk density would render them easy to handle, store and feed pressurised systems.

### Biomass Gasification

The present gasification systems are generally designed and operated to produce fuel gas for heat and power. The processes described above 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. Fundamental research is needed to improve product selectivity, to produce essentially high-purity  $H_2$ . 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 high-purity  $H_2$  would require minimal gas cleaning and separation to produce pure  $H_2$ . It is conceivable that direct- $H_2$  yield could be improved 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  $1100^\circ C$  ( $\sim 2000^\circ F$ ) would help develop indirectly heated reactor designs that would prevent products of combustion from contaminating steam or 'recycled product gas.'

Small-scale, low-cost air enrichment is another technology that will be beneficial to produce hydrogen production from biomass.

### 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 vapour-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 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 cooling and design of appropriate heat exchangers have become the focus of the recent Essent/AMER and ARBRE biomass gasification demonstration projects, for co-firing and power generation applications. In the development of high-efficiency gasification systems, it may be necessary that most if not all of these gas handling and gas clean-up R&D should be conducted at elevated pressures that match with the end-use for product  $H_2$ .

Gas cleaning R&D should also investigate  $CO_2$  removal at high temperatures, although it may not be required for biomass gasifiers that may be developed for molten carbonate fuel cells. Physical and ionic separation membranes that can separate  $H_2$  at high temperatures would be useful to produce high-purity  $H_2$ , while CO or gaseous hydrocarbons are being chemically converted to  $H_2$ .

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 to some other location downstream from the gasifier, requiring expensive treatment of all process effluents.

**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. Examples of the latter include issues related to coupling gasifiers with high-temperature fuel cells.

**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.

**Information Dissemination and Policy**

To promote the successful development and commercialisation of biomass gasifiers for hydrogen production and utilisation, 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 commercialising 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. 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.

**References**

- 1 International Energy Association 1997, 'State of the Art of Biomass Gasification, Prepared by European Concerted Action, Analysis and Coordination of the Activities Concerning Gasification of Biomass', AIR3-CT94-2284 and IEA Bioenergy, Biomass Utilisation, Task XIII, Thermal Gasification of Biomass Activity, Canadian Country Report
- 2 Paisley, M.A., and Overend, R.P., 2002, 'The SylvaGas Process from Future Energy Resources – A Commercialisation Success', 12th European Biomass Conference, June 17-21, 2002, Amsterdam, The Netherlands; [www.fercoenterprises.com/downloads/Amsterdam%20020619.pdf](http://www.fercoenterprises.com/downloads/Amsterdam%20020619.pdf)
- 3 Momtaz N. Mansour, Ravi R. Chandran and Lee Rockvam, The Evolution of and Advances in Steam Reforming of Black Liquor, Manufacturing and Technology Conversion International, Inc., [www.tri-inc.net/EvolutionSR.pdf](http://www.tri-inc.net/EvolutionSR.pdf)
- 4 Spliethoff, H. 2001, 'Status of Biomass Gasification for Power Production', IFRF Combustion Journal, Article No. 200109
- 5 Contact: Suresh P. Babu, Gas Technology Institute, 1700 South Mount Prospect Road, Des Plaines, IL 60018, USA, E-mail: [suresh.babu@gastechnology.org](mailto:suresh.babu@gastechnology.org)
- 6 Rauch, et.al, 2004, 'Steam Gasification of Biomass at CHP Plant in Guessing - Status of the Demonstration Plant,' Second World Conference and Technology Exhibition, Biomass for Energy, Industry and Climate Protection, May 10-14, Rome, Italy. [www.gastechnology.org/iea](http://www.gastechnology.org/iea)
- 7 International Energy Association 1997, 'State of the Art of Biomass Gasification, Prepared by European Concerted Action, Analysis and Coordination of the Activities Concerning Gasification of Biomass', AIR3-CT94-2284 and IEA Bioenergy, Biomass Utilisation, Task XIII, Thermal Gasification of Biomass Activity, Sweden Country Report

8 Consonni, S., Larson, E.D., Kreutz, T.G., and Berglin, N. 1998. Black Liquor-Gasifier/Gas Turbine Cogeneration. *ASME J. Engng. for Gas Turbines & Power*, Vol. 120, pp.442-449.

9 CHRISGAS 2004. [www.chrisgas.com](http://www.chrisgas.com)