2 May 2005

OBSERVATIONS ON THE CURRENT STATUS OF BIOMASS GASIFICATION

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Introduction

Gasification is a process by which either a solid or liquid carbonaceous material, containing mostly chemically bound carbon, hydrogen, oxygen, and a variety of inorganic and organic constituents, is reacted with air, oxygen, and/or steam. The reactions provide sufficient exothermic energy to produce a primary gaseous product containing mostly CO, H_2, CO_2, H_2O(g), and light hydrocarbons laced with volatile and condensable organic and inorganic compounds. Most of the inorganic constituents in the feedstock are chemically altered and either discharged as bottom ash or entrained with the raw product gas as fly-ash. Unless the raw gas is combusted immediately, it is cooled, filtered, and scrubbed with water or a process-derived liquid to remove condensables and any carry-over particles. Alternatively, the raw gas can undergo either medium-temperature (350 to 400^{o} C) or high-temperature (up to gasifier exit temperatures) gas cleaning to provide a fuel gas that can be used in a variety of energy conversion devices, including internal combustion engines, gas turbines, and fuel cells. Biomass when gasified with steam and/or oxygen will produce “synthesis gas,” rich in CO and H_2, which in turn can be catalytically converted to produce high-value fuels and chemicals.

In contrast to coal, which is currently used in several commercial gasification processes,[1] biomass is more reactive and can be effectively gasified at lower temperatures than coal. However, unlike mined coal and petroleum drawn from wells, biomass resources are dispersed and heterogeneous in nature. Consequently, special solids handling and feeding systems have to be designed, taking into consideration the heterogeneous nature and the low bulk density of biomass. The fibrous nature of herbaceous feed stocks means they are more difficult to handle than woody biomass. Another frequently encountered problem is the low-ash fusion temperatures of certain biomass, particularly under reducing conditions, which require special care in the design and operation of biomass gasifiers.

Early Commercial Ventures of Biomass Gasification

Gasification of biomass rose to some prominence during the mid-1940s when the product gas was used to fuel automobiles in order to conserve imported oil. In the following three decades, the small portable gasifiers were improved in design and small-scale biomass gasification (BMG) plants were built for a variety of heat and power applications. The most notable of these efforts include the nine Bioneer biomass gasifiers built in Finland and Sweden during 1982-86. During the same period, low-pressure circulating fluidised bed (CFB) combustors were modified by Ahlstrom (now Foster Wheeler Corporation) and developed to operate as Pyroflow gasifiers.[2] Four such gasifiers, 17 to 35 MWth capacity, were built in Finland, Sweden, and Portugal. Used mainly for replacing the then prevailing costly fuel oil for firing lime kilns and for other thermal needs in a paper mill, these units provided significant economic benefits. The first commercial 35 MWth Pyroflow gasifier installed in 1983 at Wisaforest Oy paper mill in Pietersaari, Finland, was decommissioned in 2004 after more than 20 years of successful application for firing rotary kiln lime calcinations. In 1987, Kvaerner and Götaverken developed a CFB gasifier that operated successfully at the Väro paper mill in Sweden.[3]

Other notable commercial BMG plants that were developed during this period include the first-of-a-kind commercial BMG projects in Canada, Italy, and Austria. During the 1980s, Canada successfully developed the Biosyn Process,[4] a pressurised (1.6 MPa) fluidised bed, oxygen-blown BMG process, at 10 TPH capacity to produce synthesis gas for methanol production. Commercial pursuit of the Biosyn Process was terminated in 1988 when it was established that it could not compete with the price of methanol from fossil fuels. Two TPS/Studsvik CFB gasifiers, each with 15 MWth capacity, were built and operated intermittently by Ansaldo Aerimpianti[3] with RDF pellets near Florence, Italy. The future of this plant remains uncertain. In 1987, Lurgi built a 35 MWth CFB BMG at a paper mill in Pöls, Austria.   However, because of the undesirable contamination of the lime with the ash contained in the fuel gas, the gasifier was not operated continuously and it is now used for testing and evaluation purposes only.[5]

The Next Generation of BMG Demonstrations

During the last 20 to 25 years, a significant research and technology development and demonstration effort has been launched both in Europe and North America. The following is a summary of selected scale-up efforts which are broadly representative of the current status of BMG.

Demonstration of Circulating Fluidised Bed BMG Processes

Since the mid-1980s, and subsequent to the three Ahlstrom/Foster Wheeler Corporation (FW) BMG plants discussed above, FW has successfully scaled-up the CFB BMG process to 45 MWth capacity and built the Lahden Lämpövoima Oy Kymijärvi co-firing power plant in Lahti, Finland. Starting in early 1988, the plant has been operated from 40 to 70 MWth capacity, for over 30,000 hours with greater than 97% availability.[6]

Between 1993 and 1999, Sydkraft Ab adopted the FW CFB gasification process to develop and demonstrate the first pressurised Bioflow BMG 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 8,500 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 3,600 hours. Following a recent successful bid for support from the DG Energy and Transport of the European Commission to demonstrate IGCC operation with RDF and tyre derived fuel (TDF), Sydkraft and Helector S.A., and CRES, Greece, are proceeding with re-commissioning the moth-balled demonstration plant. The facility is scheduled to launch the CHRISGAS project, a multi-national consortium technology development and demonstration 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.[8]

In 1993, Yorkshire Water was awarded a contract from the EU and others to build the TPS/Studsvik CFB BMG plant for power generation using short-rotation coppice biomass feedstock, conventional gas cleaning, and a Typhoon gas turbine to generate 8 MWe, at Eggborough, North Yorkshire, UK (i.e., ARBRE Project).[7] Starting with plant commissioning in 2001, several design and operational problems were encountered. Due to certain design inadequacies in detailed engineering and related operational issues, the primary raw gas heat exchanger overheated and promoted plugging with carry-over solids. Hence, the plant could not be operated for extended periods. The problems were compounded when financial pressures resulting from change of ownership, etc., did not provide the support needed to remedy the design and operational issues. When the project was terminated during the latter part of 2002, the plant operations provided valuable insight into project management, engineering design, and operational issues.

Lurgi has scaled-up the Pöls, Austria CFB gasifier design to an 85 MWth BMG plant built for Essent /AMER in Geertruidenberg, the Netherlands.[9] This co-firing (in a pulverised coal (PC) boiler with a total capacity of 600 MWe) project has been reactivated after some modifications to the downstream heat-exchanger to test and evaluate gasification of demolition wood. One of the operational modifications was to maintain the raw gas handling temperature at 400 to 450^{o}C to minimise condensation in the downstream heat-exchanger. Under these conditions, most of the heavy metals (e.g., Pb and Zn) and alkali compounds condense on the entrained solids which are subsequently removed in a cyclone separator. The cyclone separator is estimated to operate at 65 to 70% efficiency.

Battelle/FERCO has scaled-up the dual CFB SylvaGas process from the 10 TPD, PDU to a 200 TPD demonstration plant at the McNeil Power plant near Burlington, Vermont, USA. In late 2000, continuous operation of the plant was demonstrated with feed rates up to 320 TPD to produce an 11-14 MJ/Nm^3 (450 to 500 Btu/SCF) synthesis gas with carbon conversions approaching 80% in the gasifier. FERCO is actively pursuing commercialisation of the SylvaGas Process.[10]

Demonstration of Bubbling Fluidised Bed (BFB) BMG Processes

FW has also built and successfully operated a 50 MWth BFB gasifier at the Corenso recycling plant in Verkaus, Finland. The plant has been operating successfully for over three (3) years by gasifying 15% by weight of aluminium-containing plastic rejects and recovering about 2,500 TPY of aluminium.

The Renugas® Process, developed by IGT/GTI was scaled-up from a 12 TPD process development unit (PDU) to a 100 TPD bagasse gasification plant in Maui, Hawaii, USA. The project demonstrated limited success with air-blown gasification at about 20 bar and hot-gas filtration to remove carry-over dust. Serious problems were encountered in handling and feeding the low-density, shredded biomass into the gasifier. The project was terminated in 1997.[11] In January 2005, GTI completed the shakedown of a new 24 TPD, adiabatic Flex Fuel Test Facility in Des Plaines, Illinois. This state-of-the-art test platform can be operated either as a BFB or CFB for both BMG and biomass combustion. The facility is capable of operating at pressures up to 25 bar and can process all types of carbonaceous fuels.[12]

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.[13] Around 1993, Carbona successfully operated the pressurised gasifier for over 2,000 hours with a variety of biomass wastes and also evaluated hot-gas filtration for IGCC application. In October 2004, Carbona reported that ground had been broken for building a 5.4 MWe capacity low pressure, Renugas demonstration project in Skive, Denmark. The project will start its operations with pelletised wood.

Demonstration of Moving-bed BMG Processes

A recent notable development in BMG is the evolution of the Novel Gasification Process[14] by the original developers of the Bioneer Gasification process in Finland. The novelty involves forced fuel-feeding into the mid-section of an updraft gasifier. This should help in feeding low bulk-density herbaceous biomass fuels, such as crop residues, without the need for pelletisation. Further, the air used for gasification is strategically introduced into the top third of the gasifier bed along with steam-laden exhaust flue gases from the downstream gas engines. The upper part of the gasifier is maintained at 850^{o}C to produce a fuel gas low in tar. The product gases pass through a catalytic tar destruction unit maintained at 900°C. Tests with Ni monolith have shown significant tar destruction and thermal decomposition of 70% of NH_3 contained in the fuel gas. The product gas is scrubbed to remove the residual tar, NH_3, and HCN. The clean fuel gas is subsequently fed to a JMS 316 Jenbacher Engine to produce electricity at 30-36% efficiency. The CHP demonstration, at Kokemaki, Finland provides 1.8 MWe and 4.3 MWth heat to about 8,500 people. Plant start-up is scheduled for the first quarter of 2005.

Since 1994, Denmark has invested significant resources to improve the operational reliability of the 5 MWth, Vølund BMG process installed and operating as a CHP demonstration project at Harboore, Denmark. The updraft moving bed gasifier employed at this facility produces a significant quantity of condensate. The process employs a combination of scrubbing and wet electrostatic precipitation to remove carry-over condensable hydrocarbons and to supply clean fuel gas to two 648 kWe Jenbacher gas engines. The tar separated from the aqueous media is gasified, particularly during peak energy demand by injecting it into the combustion zone of the gasifier. The Vølund demonstration includes the development of a complete condensate treatment system without any harmful wastewater discharge.[15]

The UK Department of Trade and Industry has supported the successful development of small-scale BMG in Northern Ireland for power generation. These include the 100 kWe Brookhall Estate and the 400 kWth and 200 kWe CHP demonstration by Exus Energy (formerly B9 Energy systems) at the Blackwater Valley Museum. Both employ down-draft BMG processes. The other significant small-scale BMG technology development and commercialisation activity in the UK is being pursued by Wellman Process Engineering Limited in West Midlands.[16] The Belgian company, Xylowatt, A.S. (XW)[17] has recently built five downdraft BMG power generation modules, each able to produce 300 kWe and 600 kWth in CHP applications. The Swiss company, Xylowatt A.S.,[18] is testing and evaluating the open-top Indian Institute of Science downdraft gasifier in Bulle, Switzerland at a feed rate of 54 kg/h.

In the USA, the Community Power Corporation developed portable open-top downdraft moving bed gasifiers that can discharge ash without a mechanical grate. In this system, secondary air is introduced into the char bed to burn-off tars and to maintain a desired temperature profile in the gasifier. A 22 kWe gasification gas engine system has been demonstrated at Aliminos in the

Philippines with coconut shells.[19] Similar units were also tested and demonstrated in the USA for other applications.

Demonstration of Multi-stage, Indirectly Heated and Other Types of BMG Processes
The BMG technology development and demonstration efforts continue to focus on resolving the issues related to tar contained in raw gases and are producing a medium calorific value (MCV) synthesis gas without the use of oxygen. To address these issues, gasifiers were developed with distinctly separate drying, devolatilisation, gasification, and combustion reaction zones and employing innovative thermal integration of these zones to produce a MCV synthesis gas.

The two-stage, combined fluidised bed gasifier and CFB combustion process developed by the Technical University of Vienna (TUV), Austria, with Repotec has demonstrated exceptional rapidity of success in scaling-up the laboratory scale unit to a commercial demonstration plant.[20] The characteristic features, progress and performance of the TUV Güssing demonstration for CHP are widely published. 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 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 BMG. The clean gas is then introduced to a 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 has logged in more than 14,000 hours and the total operating time with the integrated gasifier and gas engine is about 11,000 hours.

In the low-pressure Choren/Carbo-V Process,[21] the tar-rich gases are separated from the char produced in a low-temperature gasifier and both streams are introduced into an entrained slagging gasifier to achieve nearly complete tar destruction and carbon conversion to desirable product gases. After conducting extensive tests between 1998 and 2001 in a 1 MWth pilot plant, Choren reported that the process produces a tar-free gas without the use of any catalysts. Other Choren milestone accomplishments include 12,000 hours of operation and successful integration of the gasifier with gas engines. By using oxygen as the oxidant the process should be able to produce synthesis gas suitable for conversion to liquid fuels.

The Technical University of Denmark (DTU) developed a two-stage process[22] involving an indirectly heated pyrolyser followed by a char gasifier. The pyrolysis products are subjected to partial oxidation by air in a narrow zone between the pyrolyser and the char gasifier. The product gases pass through the hot char bed where most of the residual tar is decomposed to gaseous products. After heat recovery and bag-house cleaning, the product gases are fed to a gas engine to produce power. A 75 kWth BMG capacity system was developed and successfully demonstrated as the Viking Gasifier at DTU. During 2,000 hours of operation, dust removal was estimated to exceed 99.5% and a clean fuel gas was produced with <5 mg tar/Nm^3. The Viking gasifier and the gas engine were equipped for automated and unattended operation.

In the last few years, TK Energie[23] has demonstrated a three-stage (pyrolysis, combustion, and gasification) process. The air-blown process consists of an inclined pyrolyser discharging the products into a partial oxidation zone, and a reformer-based char gasification zone with a rocking grate for ash discharge. The two gasifiers were designed for 833 kWth (for Japan) and 3.125 MWth (for Denmark) capacities, and evaluated for process performance. The estimated thermal efficiencies for these plants are 60 and 56%, while the electrical efficiencies are estimated to be 24 and 32%, respectively. The gasifiers are designed for 7,000 hours of continuous operation. So far, the Japanese gasifier has been operated for about 200 hours and the Danish gasifier for a total of 1200 hours. Performance observations include about 3-10% of char-loss, throughputs up to 2 $MWth/m^2$ of grate area, and an overall thermal efficiency of 70 to 80%. In the initial tests, the gasifiers were satisfactorily operated for the first 200 hours. Around 500 hours of operation, the gasification system required some mechanical repairs. Problems were generally encountered in the biomass feed system, handling tar-laden gases, and in preventing air leakage into the system.

Other multi-stage gasifiers, which burn the product gas in combustors located at arms-length from the gasifier, are the Compact Power Co. and PRM Energy Systems Inc. The Compact Power Co., in the UK[24] has developed a process that employs effective thermal integration of pyrolysis, gasification, and high temperature oxidation zones to convert a wide range of wastes, including biomass, to fuel gas and other usable products (e.g. carbon of various grades and types). For over two years, a 1.8 MWth (8000 TPY of waste capacity) commercial plant has been in continuous operation at Avonmouth, Bristol, UK. The PRM systems[25] are essentially staged combustion units with no significant benefit in thermal efficiency compared to conventional burning. PRM has built eighteen plants ranging in capacity from 5 to 90 MWth in the USA, Italy, Malaysia, and Costa Rica and most of them are in commercial operation. These units have handled a variety of crop residues, such as rice hulls, rice straw, wheat straw, corn cobs and stubble, and peanut hulls; and waste materials including chicken litter, green bark, sawdust and chips, peat, RDF (fluff, flake and pellet), petroleum coke, cotton gin waste, cotton seed hulls, and low grade coal.

A notable development in BMG worth reporting is the commercial scale co-gasification of biomass and coal demonstrated at the 250 MWe NUON Power Plant in Buggenum, The Netherlands.[26] Co-gasification tests were conducted in the Shell gasification process with up to 30% by weight of biomass. Besides gasification of demolition wood, tests were also conducted with chicken litter and sewage sludge. The scope of the test campaign includes investigation of biomass contaminants on product gas and ash quality.

Research to Resolve Technical Hurdles

On-going research, technology development and demonstration efforts have addressed and resolved several hurdles to advance BMG. However, progress in scale-up, exploration of new and advanced applications, and efforts to improve operational reliability, have identified new hurdles to advance the state-of-the-art of BMG.

In general, the technical hurdles include handling of mixed feed stocks, high-pressure solids feeders and ash discharge systems; real-time monitoring and timely control of critical gasifier operational parameters; minimising tar formation in gasification; hot gas particulates, tar, alkali, chlorides and ammonia removal; heat recovery; conventional gas clean-up, waste water treatment, and effluent management; and process scale-up. It should be noted that any technical advancement in the investigation of individual unit operations or unit processes does not guarantee successful scale-up and application of these innovations, primarily for first-of-a-kind demonstration projects.

The recent advances in resolving certain selected technical hurdles are given below:

Solids Handling and Feeding

Feeding biomass solids to gasifiers, in particular herbaceous materials, remains a formidable challenge. Thomas Koch (TK) Energi AS, in Denmark reports developing a high pressure single-stage piston feeder that can operate against 40 bar pressure and at feed rates up to 4 TPH.[27] The piston feeder compresses the fuel through a tapered opening thus creating high radial pressure in the fuel plug. The feeder is designed in such a way that by releasing the piston to feed the next batch of fuel, the plug will stay in its position. Ultimately, the dense plug is disintegrated before discharging the feed into a pressurised gasifier. The Sugar Research Institute in Australia claims to have developed a feeder based on the principle of squeezing juice from sugar cane. There are no further details readily available on this feeder.[28] If successful, feeders of this type will circumvent the need for lock hopper compression gases and significantly improve the reliability and reduce the cost of biomass feeding.

Gas Clean-up and Gas Conditioning

Research continued in Europe to understand and model tar formation and destruction in the BMG reactor as well as in a catalytic reactor operating in series with the gasifier. Recent studies conducted at the National Bioenergy Center of NREL (NBEC/NREL) have evaluated several catalysts, including the BCL D4 catalyst, and concluded that the best option for tar destruction is to employ calcined dolomite or olivine in the gasifier as the primary tar decomposition agent followed by a secondary or polishing tar destruction step with a Ni based catalyst.[29] VTT has shown that tar decomposition was effectively achieved using Ni monolith substrates installed immediately down-stream from the gasifier. Although Ni has the capability to reform or decompose condensable hydrocarbons and even ammonia, at about 800^{o}C, Ni catalysts are vulnerable to sulphur, chlorine, and alkali metals. Consequently, research continues to explore the use of other catalysts containing zirconia and copper. Meanwhile, there is merit in investigating the tolerable quantities and types of condensable hydrocarbons and other contaminants in product gases for subsequent gas processing or energy conversion (i.e., risk management). More detailed discussions of the issues related to tar decomposition and reforming have already been published.[30, 31, 32]

Around 2001, ECN started the development of OLGA gas cleaning process, employing an organic scrubbing agent to remove tars from raw product gases above the water dew point. The water-free, organic liquid stream can be recycled to the gasifier to thermally decompose and gasify the tars. So far, laboratory-scale and pilot-scale tests, up to 0.5 MWth capacity, have proved the technical viability of the concept.[33]

Besides tar, the other significant raw gas contaminants include alkalis, ammonia, chlorides, sulphides and particulates. Regenerable and non-regenerable solid materials and physical and chemical absorption liquids can effectively remove sulphides and ammonia. Operating procedures with staged gas cooling have proved to be successful in removing alkalis and chlorides along with particulate matter as they are separated using cyclones and barrier filters. Both ceramic and sintered metal barrier filters have been developed and demonstrated to remove particulate matter in raw gases. Future research in hot gas clean-up and conditioning may also include the development of catalytic barrier filters that can decompose the tar compounds or adjust gas composition (e.g., H_2 to CO ratio) while the separation of entrained particulates is in progress. For some applications flexible ceramic bag filters that are now being developed will offer an attractive alternative to the fragile barrier filters.

Closely related to hot-gas clean-up research is the increasing interest both in Europe and the USA in investigating the optimal means of integrating BMG and gas clean-up systems with high-temperature fuel cells. The recent NBEC/NREL study[29] recognises that due to the variability in biomass feedstock composition (until a reliable biomass, feedstock supply infrastructure can be developed with good QC/QA measures), it is likely that gas clean-up systems may have to be designed for site-specific applications.

For low-temperature fuel gas utilisation applications, gas scrubbing with water or organic liquids can effectively remove all types of fuel gas contaminants. The Vølund CHP demonstration project at Harboore, Denmark has shown that wet electrostatic precipitators can effectively provide clean fuel gas to gas engines.

Another important aspect of gas conditioning is the recovery of high-temperature sensible heat from raw product gases employing heat exchangers. These heat exchangers should be constructed with corrosion resistant materials to prevent fuel gas and air leakage. Lessons learnt from recent demonstrations also include the need to design these heat exchangers so that the particulate matter entrained with the raw gases passes through and does not lead to blockage. In this regard, it is equally important to select tested and evaluated robust tar decomposition additives or catalysts which do not contribute to dust entrainment with the product gases. It is also imperative to follow a gas handling procedure that minimises re-absorption of CO_2 by additives and sorbents that may lead to agglomeration of entrained dust and blockage of heat exchanger tubes and gas transfer pipes.

The recent interest in synthesis gas production and co-production of liquid fuels, hydrogen, chemicals and fertilisers may provide the impetus needed to find new and value-added applications for BMG. However, it should be noted that synthesis gas conversion catalysts require one to two orders of magnitude less tar than is generally specified for gas engines and in general for power generation.

In concluding this section on research, it is useful to note that in November 2002, ExxonMobil, Toyota, Schlumberger, and GE launched The Global Climate and Energy Project at Stanford University, Stanford, CA, USA.[34] This project is expected to receive $225 million over a 10 year period for coordinating pre-commercial research to develop technology options with reduced greenhouse gas emissions. It is conceivable that innovative proposals involving BMG could very well be considered for funding by this project.

Some Perspectives on the Path Forward

Despite the widely acknowledged benefits, commercialisation of BMG has fallen short of expectations. The reasons include absence of market pull due to competition from conventional fuels, inadequate government policies and incentives for BMG projects, lack of infrastructure for quality controlled feedstock supply at a guaranteed price, and the inability to obtain performance guarantees by many technology developers.

In some European countries where incentives for building and operating BMG exist, projects have been deployed with varying degrees of success. While waiting for efficient and economical BMG processes to be developed, it is worthwhile to adopt measures to develop the infrastructure for feedstock supply. Towards this end, governments could implement policies to stimulate rural economies by providing incentives on growth and harvest of biomass for energy production. In addition, development of co-combustion and co-firing, and deployment of on-site power generation with gasifiers and gas engines for remote locations with access to biomass, should lay the foundation for a reliable feedstock supply system. In many countries, with access to natural gas and oil, a significant portion of these fuels is used for mundane industrial applications. BMG fuel gas can readily replace fossil fuels for such applications with little or no burner modifications. Therefore, in regions with access to biomass, it is advisable to explore the application of BMG for industrial heating. These opportunities should improve energy security while simultaneously creating jobs and developing the much needed fuel supply infrastructure.

Some entrepreneurs have been able to launch gasification technologies using waste materials to produce value-added products. In such cases, the negative price of waste materials provides the financial incentive for project implementation. The added benefit is extending the life of landfills or eliminating them in the future. The launching of a waste gasification industry will also lead to the development of robust feed-handling systems and advanced gas and wastewater cleaning schemes that could be directly applied to BMG. Technically successful waste gasification schemes are demonstrated by Burgau facility in Germany, the Mitsui R21 in Japan, Compact Power process in the UK. The performance of the Sekundarrohstoff-Verwertungszentrum Schwarze Pumpe GmbH (SVZ)[35] plant in Germany is well known. The know-how developed during waste gasification should ultimately help improve the reliability of BMG plant design and operations.

Recently, three new strategic partnerships were launched in Europe to pursue waste and biomass gasification for a variety of energy conversion applications. The first partnership is the recently announced set-up of the Vaxjo Värnamo BMG Center at Värnamo, Sweden employing the Sydkraft Ab/FW CFB pressurised gasification process as the ‘centre-piece.’

The second partnership involving CHOREN FUEL GmbH & Co. KG, German Economics Ministry, DaimlerChrysler AG, Volkswagen AG, and Sud Chemie, located in Freiberg, Saxony, Germany, is currently pursuing the manufacture of renewable synthetic fuels from biomass utilizing the Carbo-V Process. The projected €400 million team effort has set a goal to produce by 2007, “green” SunDiesel at an estimated cost of €0.69/litre.

The third partnership is led by FUTURE ENERGY GmbH, which is also located in Freiberg, Germany. From website information, FUTURE ENERGY has acquired certain rights to the SVZ, Schwarze Pumpe gas works technology and know-how, and entered into a partnership with Forschungzentrum Karlsruhe (FZK), Technical University of Karlsruhe (TUK), and perhaps with others. One of the missions of this partnership is to pursue the development of the GSP process. Initially conceived at TUK, it employs a twin-screw fast pyrolysis reactor to convert crop residues producing transportable liquids to produce synthesis gas at a central reforming plant. Partnerships of this type may be the mechanism by which risk can be shared. In the current environment, strategic relationships may be vital to launch the next round of commercial BMG plants.

With the formal implementation of the Kyoto protocol on Wednesday February 16 2005, considerable support should be forthcoming to advance BMG RD&D. It is possible that with the introduction of supporting policies and incentives, the opportunities for BMG commercialisation should steadily improve. Such commercialisation initiatives should include sustained commitment from the principals to finance and support RD&D required to resolve the technical hurdles that normally arise during scale-up and demonstration of first-of-a-kind, high-efficiency BMG processes. The results from a robust RD&D programme should improve reliability of operation, process optimisation, and hence the overall process economics. These are essential ingredients to develop technology commercialisation investments backed with process performance guarantees.

The extensive global commitment made during the first half of the 20th century to exploit the utilisation of coal, oil, and gas have led to the economic prosperity witnessed during the latter half of the 20th century. It is now necessary to commit investments similar to those made a century ago, for biomass and other renewable energy resources, to retain and nurture the current economic prosperity and at the same time to promote sustainable environmental protection and to further improve the quality of life.

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Abbreviations

BMG	Biomass Gasification
Btu	British thermal unit(s)
BFB	Bubbling Fluidised Bed
CO	Carbon monoxide
CO_2	Carbon dioxide
CFB	Circulating Fluidised Bed
CHP	Combined Heat and Power

GSP	Gaskombinat Schwarze Pumpe
HCN	Hydrogen Cyanide
H_2	Hydrogen
H_2O	Water
$H_2O(g)$	Steam
IGCC	Integrated Gas Combined Cycle
kWe	kilowatt electric
kWh	kilowatt hour
kWth	kilowatt thermal
MCV	Medium Calorific Value
mg	milligram
MJ	Megajoules (10^6 joules)
MJ/Nm^3	Megajoule per Normal cubic meter
MPa	Mega Pascal
MWe	Megawatt electric
MWh	Megawatt hour
MWth	Megawatt thermal
N	Nitrogen
Ni	Nickle
NH_3	Ammonia
Pb	Lead
PC	Pulverised Coal
PDU	Process Development Unit
QC	Quality Control
QA	Quality Assurance
RDF	Refuse Derived Fuel
SCF	Standard Cubic Foot
TDF	Tyre Derived Fuel
TPH	tonnes per hour
TPD	tonnes per day
TPY	tonnes per year
Zn	Zinc

Acknowledgement

Dr Babu is Assistant Vice President, Research and Deployment at the Gas Technology Institute (GTI), Des Plaines, Illinois, USA. During his approximately 30 years at GTI, he has worked on all aspects on thermal conversion of coal and biomass as well as natural gas utilisation and has particular expertise in high pressure conversion technologies. At the 2nd World Biomass Conference in May 2004 in Rome, Dr Babu was awarded the David Hall World Prize for Bioenergy in recognition of his long involvement in biomass conversion technologies and for his leadership in the gasification RD&D area. The Executive Committee of IEA Bioenergy is appreciative of this comprehensive overview paper prepared by Dr Babu.