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GASIFICATION TECHNOLOGY: TECHNICAL ISSUES IN THE DESIGN OF GASIFIERS FOR THE AUSTRALIAN SUGAR INDUSTRY

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Abstract

Use of cane processing wastes in a combined cycle gasification power plant offers the potential to increase the electrical export capacity of Australian sugar factories from the current 64 MWe (predominantly seasonal) to 3400 MWe (year round). The Sugar Research Institute (SRI) is a member of the Queensland Biomass Energy Group (QBEG), formed to develop cogeneration options and gasification technology for use in the sugar industry. A detailed study has been undertaken which underpins the activities of QBEG. These activities include the design and construction of a gasification demonstration plant to be located at a Queensland sugar factory in the near future. The relevant technical and financial data for power generation at a nominal 600 tonnes cane per hour (tch) sugar factory are outlined for a number of different operational scenarios. The aim of this paper is to review the technical hurdles in the development of Biomass Integrated Gasification/Combined Cycle (BIG/CC) technology with specific relevance to the gasification of cane wastes (bagasse and cane trash), and the technical and practical issues arising from a recent technology review. Preliminary studies so far undertaken by SRI are discussed. The QBEG BIG/CC research plan is outlined. This is targeted at overcoming the identified technical problems and using this knowledge in the design of a demonstration-scale BIG/CC power plant.

Introduction

The Sugar Research Institute is a member of the Queensland Biomass Energy Group (QBEG), formed to develop cogeneration options and gasification technology for use in the sugar industry. A detailed study has been undertaken which underpins the activities of QBEG, (Dixon *et al.*, 1998). These activities include the design and construction of a gasification demonstration plant to be located at a Queensland sugar factory in the near future. As a matter of interest, a similar project is at a similar stage of development in Brazil, Centro De Technologia Copersucar (1998).

Currently, the electricity export capacity of the Australian sugar industry is approximately 64 MWe, which is predominantly available during the crushing season only (Hobson, 1998). Dixon *et al.* (1998) have examined the potential for Biomass Integrated Combined Cycle (BIG/CC) power generation and compared this to current cogeneration technologies. It was found that BIG/CC has the potential to increase the export capacity of Australian sugar factories to 3400 MWe at around 75% availability (24 hours per day during a nominal 6 months crushing season and 16 hours per day and 5 days per week during the off season).

In comparison, the potential output from conventional high pressure steam cycle cogeneration plants is less than half this amount and conventional low pressure steam cycle cogeneration around one third, for the same fuel utilisation.

Dixon *et al.* (1998) reviewed a number of fuel scenarios to examine the options for a year-round power export operation. To illustrate the possible extremes, Table 1 shows some indicative values for an average 600 tch sugar factory with a steam economy of 45% steam on-cane, for three of the 24 scenarios examined, namely:

- BIG/CC with bagasse and cane field trash used as an off-season fuel, (the amount of trash left in the field after harvesting is equal to roughly twice the amount of

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bagasse that currently finds its way to the factory, on a dry basis—Burnham, 1993). The figure for the Australian industry may be somewhat less, due to different agronomic and harvesting practices; approximately half of this material may be available for use as fuel without major agronomic impact.

- BIG/CC with natural gas alone used as an off season fuel.
- High pressure (6000 kPa) steam cycle with trash used as a supplementary fuel.

The interesting aspects to note from the data in Table 1 are:

- The power export levels and the size of capital investment are both 20–40 times greater than typical sugar factory experience.
- Provided a steam economy of at least 45% on-cane is maintained, minimal conventional boiler capacity is required in a factory with a BIG/CC power plant, due to the steam provided by a heat recovery steam generator (HRSG) located in the gas turbine exhaust. An additional benefit is that steam can be provided year-round for annex processes such as sugar refining. This has significant implications for the implementation of BIG/CC in factories with existing boilers. This is discussed subsequently.
- Massive bagasse and/or cane trash storage is required for year-round operation under many scenarios, unless a balance is struck between the use of supplementary fuels, such as natural gas, and stored bagasse or trash. A reduction in off-season power generation is unattractive because it results in an under-utilisation of the installed capital.
- The revenues from BIG/CC do not make it an obvious choice when compared to high pressure steam cycles, but BIG/CC does become much more attractive if electricity selling price increases above $65/MWh.

Table 1—Indicative data for a BIG/CC power plant located at a 600 tch sugar factory with a steam economy of 45% on-cane.

	Crush season	Maintenance period
Nominal export capacity (MWe) and efficiency on a HHV basis.	(a) 207 @ 31% (b) 134 @ 30% (c) 67 @ 12%	138 @ 38% 141 @ 41% 86 @ 20%
Approx. installed capital cost $M; including $2 M to achieve 45% SOC, plus $5 M for bagasse storage {(a) and (c) only}	(a) 311–414 (b) 197–267 (c) 103	
Condensing capacity requirement MWthermal (crush season figures are those in addition to the existing factory 454 MWt condensing load)	(a) 214 (b) 230 (c) 104	337 344 430
Fuel usage (a) bagasse/trash (kt) (b) bagasse/Natural gas (kt) (c) bagasse/trash (kt)	(a) 641/325 (b) 641/18 (c) 641/141	0/335 0/57 0/397
Additional boiler capacity required to supply factory during crush (tph)	(a) Nil (b) 124 (c) Nil	
Bagasse/Trash storage required (kt)	(a) 321 (b) 2 (c) 397	
GWh exported	(a) 767 (b) 497 (c) 247	331 337 206
Approx. net revenue @ $15/MWh ($M p.a.), (for comparison only)	(a) 11.5 (b) 7.5 (c) 3.7	5.0 5.1 3.1

Notes: (a) BIG/CC with bagasse and trash used as an off season fuel
(b) BIG/CC with natural gas alone used as an off season fuel
(c) Conventional high pressure steam cycle with trash used as a supplementary fuel

Figures calculated from data in Dixon *et al.* (1998). These numbers are indicative only and are subject to such factors as fuel quality and factory steam usage. Net revenue is based on an assumed selling price of $65/MWh and a cost of power generated of $50/MWh (including capital charges). The actual cost of power generated is estimated to vary from $44 to $69/MWh depending on the technology used, off-season fuel costs and year-round capital utilisation factor.

Financial incentives associated with greenhouse emission reductions will likely play a significant role in increasing selling prices from the current $40 per MWh to $65 and beyond. In this event, the higher efficiency and higher output of the BIG/CC power plant options provide a multiplying effect on the revenue stream relative to steam cycle technologies.

Technical hurdles to bagasse gasification

A technology review of large-scale gasification for power generation was reported by Hobson and Dixon (1998). This and a subsequent review have identified that the following technical hurdles have yet to be overcome to achieve commercial status for bagasse gasification.

Fuel storage and handling systems

The issues of storage area requirements and costs of handling are common to all sugar factory cogeneration options and are the subject of ongoing research. One novel possibility is to store off-season fuel in the form of a pelletised charcoal, manufactured in a modified gasification process. It has been calculated that, in terms of fuel energy stored, charcoal may require 22% the storage volume of an equivalent amount of heaped bagasse or 44% of that required for baled bagasse. The actual tonnage stored would be around one third that of bagasse, due to the higher energy density of charcoal. In addition, charcoal pellets can be expected to handle better than loose bagasse or bales and will avoid the health concerns associated with bagasse spores.

Reactor design

Development of a gasification reactor design suitable for scale-up to the 50–250 MWe range has not yet been achieved successfully for any biomass feedstock anywhere in the world. Some of the specific issues for bagasse are discussed in the next section. Bridgwater (1995) and others have noted that unpressurised reactors are more costly that pressurised reactors for plants greater than 50 MWe, due to the increased physical size of the components at this scale.

Gas clean-up for gas turbine firing

This remains an issue for most combined cycle processes, BIG/CC included. The issues here relate to the need for cleanup to occur at elevated temperatures (greater than 300 °C), to maintain cycle efficiency. At these temperatures, devices which can clean gases to gas turbine specification are still not commercially proven (although some devices are nearing this point in pressurised combustion applications, Anon., 1998). Burnham (1993) states the requirements for gas turbines as particulates less than 30 mg/Nm^3 and alkali metals (Na, K, Ca, Mg) less than 100 parts per billion (i.e., less than 0.1 mg/Nm^3). One advantage of such stringent gas quality demands for the gas turbine is that no flue gas cleanup whatsoever is required, in contrast with the onerous requirements for bagasse boilers.

Gasification product gas fuel value

Wiant *et al.* (1998) reported gasifier product gas lower heating values (LHV) of 4.7 to 6.3 MJ/Nm^3. This product gas was from the gasification of a 15–20% moisture bagasse feedstock. In comparison, the LHV of natural gas is around 40 MJ/Nm^3. Processes which utilise an integrated drying stage are more likely to experience gas LHVs in the region of 3.8 to 5.0 MJ/Nm^3, due to the dilution effect of fuel moisture in the product gas.

(Integrated drying is the process by which heat from the gases leaving the gasifier is used to vapourise the moisture in the feedstock immediately prior to gasification, via direct contact heat exchange between the hot gas stream and the incoming feedstock. While this technique has significant advantages, in terms of heat transfer efficiency and capital cost, it does result in the evaporated fuel moisture remaining with the feedstock and thus diluting the gasifier product gas.)

While fuel moisture retained in the product gas provides a greater mass flow to drive the gas turbine, a low fuel LHV can cause combustion stability problems in the gas turbine combustor. Staff at HRL Pty Ltd (pers. comm.) and others have experienced difficulties achieving stable gas turbine combustion when the gas fuel value is less than 4.0 MJ/Nm^3. Such concerns warrant the consideration of energy efficient feedstock drying processes prior to the gasification stage, as well as fuel enrichment (e.g., with natural gas or other fossil fuel), or the potential for replacement of gasification air with oxygen enriched air (to reduce product gas dilution by nitrogen in the air).

Transition to BIG/CC

A key issue for the sugar industry is how each sugar factory can make the complex transition from currently installed plant to an arrangement which includes a fully integrated BIG/CC power plant. The financially optimum path will depend on the circumstances of each individual factory, so far as the following are concerned:

- Remaining service life and pressure rating of existing boilers;
- Remaining service life of electrical distribution equipment and ability to upgrade existing alternators and grid interconnections;
- Factory specific costs of improvements in factory steam economy;
- Site issues such as space for a BIG/CC plant and the associated fuel storage;
- Availability and delivered cost of alternative off-season fuels, such as natural gas, forestry waste, coal, etc.

While all of these factors will impact greatly on the transition to fully integrated BIG/CC, the single largest issue (after electrical export infrastructure) is how the boiler station evolves. In particular, there may be significant advantage when replacing boilers, convection banks, superheaters or other heat exchange equipment, to arranging these such that they can be used in future as part of a gas turbine exhaust heat recovery steam generator.

Research to date

SRI has recently begun research to investigate the factors that will impact on the development of gasification technology for bagasse and cane trash. The following is a summary of this work to date.

Fuel storage and handling

Cane trash handling and preparation

Given that the fuel handling systems within sugar factories are already arranged to handle shredded bagasse, it is reasonable to assume that cane trash will be shredded prior to storage or final use. Mill experience and tests in SRI's Wardell hammer mill indicate that attempts to shred fresh cane trash by conventional means are likely to result in frequent feed chokes, which are substantially reduced if the trash is dried first. It also appears that minor changes to shredder hammers and shredder geometry should readily improve the shredding of cane trash.

Fuel feeding

Difficulties feeding bagasse into a pressurised gasifier arguably led to the demise of the world's first demonstration scale bagasse gasifier. (US Department of Energy funded PICTHR bagasse gasification project at Paia mill on Maui Island, Hawaii, Wiant *et al.*, 1998).

Similar problems have been experienced with most biomass feedstocks; however, bagasse is particularly problematic due largely to its fibrous nature. Some researchers attempt to circumvent this problem by pelletising the bagasse; however, Gabra *et al.* (1998) found that pelletisation can add more than US$25 per MWh to the operating cost of a gasification process. This represents an increase in the cost of electricity generated by more than 50%, which is clearly uneconomic. SRI is about to commence investigation of a number of options to overcome this hurdle.

Gasification reactor design

Fluidisation of bagasse

Most biomass gasification processes investigated to date and intended for large-scale power generation utilise fluidised bed technologies. Chong *et al.* (1992) investigated bagasse fluidisation behaviour for atmospheric fluidised bed combustion. They found that bagasse does not fluidise well due to a low particle density and broad particle size distribution. In particular, most bagasse particles tend to float on top of the fluidising media in bubbling fluidised beds, while the finer fractions are easily lost from the bed into the fluidisation gas stream. Both of these behaviours defeat the advantages of bubbling fluidised beds (i.e., rapid and even heat and mass transfer) and make bed management difficult. (Bed management refers to practices, which attempt to ensure an even distribution of the incoming feed and reactant gases throughout the bed, primarily to avoid hot spots that can occur near the oxidant inlets. Hot spots can result in localised temperatures many hundreds of degrees above the bed operating temperature and cause ash agglomeration that results in clinker accumulating in the bottom of the fluidised bed.)

Thus, SRI are investigating processes where the tendency for bagasse to entrain in a gas stream is used to advantage, while still catering for the larger size fractions. Such techniques include circulating fluidised beds, spouted fluidised beds and fully entrained flow gasification.

Effect of inorganic constituents (ash)

Many gasification processes are hampered by the buildup of ash constituents which inhibit the prolonged stability of a fluidised bed (by ash agglomeration in the bottom of the bed) or result in sticky ash deposits which foul and sometimes damage the gasifier refractory lining and items of downstream equipment. In addition, alkali metals (Na, K, Ca and Mg) must be removed before the gasifier product gas can be fired in the gas turbine. Hence, the inorganic components in the feedstock play a key role in the development of gasification technology. Table 2 outlines the results of some preliminary analyses of bagasse and trash, compared to other biomasses with regards to ash properties.

Fuel reactivity

Fuel reactivity is a key parameter in the sizing of a gasification reactor. The chemical steps in the gasification of dry bagasse under BIG/CC conditions are outlined in Figure 1, Joyce (1998).

The first step in gasification is devolatilisation. This happens in a fraction of a second at a typical gasification temperature of 800–900 °C, and in the case of bagasse results in conversion of approximately 85% of the feedstock (on an ash free mass basis). It also produces tars and chars. Tar cracking also very rapidly converts the 5% of material that initially became tars to light gases. The remaining char (15%) gasifies at a rate that is around 100–1000 times slower than the devolatilisation step. The precise rate of char gasification is a function of feedstock characteristics, temperature history, operating pressure and the gas composition in the gasifier. (Reported char gasification rates vary by approximately a hundred-fold at the same temperature for chars derived from feedstocks such as bagasse, woods and coals.)

Char gasification rate is complicated by the catalytic behaviour of the ash components, particularly if these accumulate in the gasifier. Characterisation of the gasification rate of bagasse and cane trash chars is the subject of work that has recently commenced at SRI, in collaboration with the University of Queensland.

Future research

The following is a summary of the QBEG research plan. The plan has been formulated to address the technical hurdles that must be overcome to enable construction of a demonstration BIG/CC power plant of 7 MWe total capacity in the near future.

- Detailed engineering technology review and selection of gasification technology components.
- Pilot plant gasifier trials. These will assess and examine the selected gasification technology.
- Cogeneration cycle, industry cost and sugar factory steam economy studies. This will

Table 2—Some preliminary comparisons of the characteristics of bagasse and cane trash ash with ash derived from other fuel sources.

Material	Wt% ash (dry basis)	Sintering/softening (agglomeration) temperature (°C)	Alkali species as wt% of total ash (taken as oxide forms)
Bagasse * including dirt excluding dirt	6 2	1510 >1100 (est.)	4 14
Trash * including dirt excluding dirt	15 8	1140 1100	9 23
Bagasse (typical reported values) [a, b, c]	2–15	> 1000	3–12
Straws (typical reported values) [b,c,d,e]	2–5	600–1000	8–40
Wood (typical reported values) [b,c,d,e]	0.1–2	> 1150	7–25
Black coals # (typical reported values) [c, f, g, h, i]	10–25	1000 – >1600	5–15

* A single set of samples taken in September 1998 from the Mackay region and analysed by SRI and ACIRL. Both the bagasse and trash are from the same farm and block. The sintering temperature of these was measured under a reducing (gasification) atmosphere. The other reported values refer to sintering under an oxidising atmosphere. Sintering temperatures are usually lower under reducing conditions.

Brown coals exhibit a wide range of ash contents, generally have much higher alkali contents and exhibit a wider range of (generally lower) sintering temperatures.

a. Rao (1997), b. Miles *et al.* (1995), c. Burnham (1993), d. Acaroolu and Aksoy (1998), e. Reisenger *et al.* (1996), f. Hurst *et al.* (1997), g. Laughlin and Sullivan (1997), h. Stutzman and Centeno (1995), i. Harris *et al.* (1996).

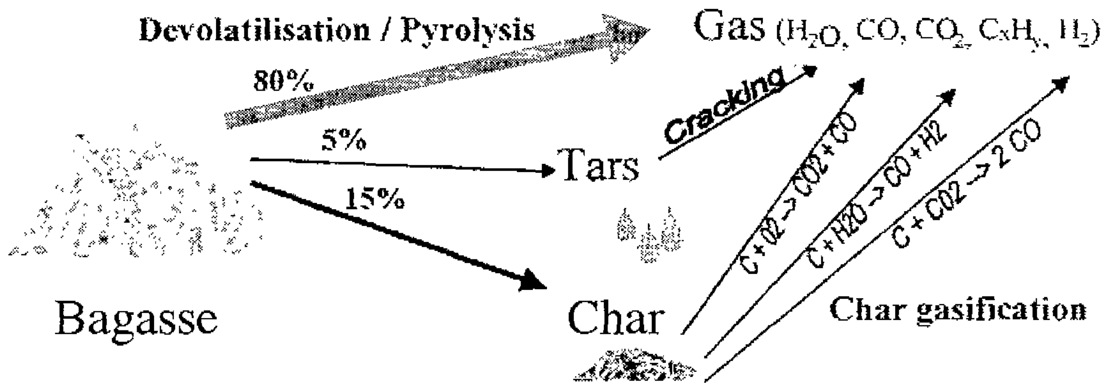

Fig. 1—The gasification process of bagasse.

include the development of optimum plant configurations for integration into sugar factories and optimum upgrade routes to progress to fully integrated BIG/CC.

- Bagasse feeding development. Development and proving of a feeder suitable for scale-up to 5–250 MW gasification plant designs.
- Ash characterisation studies. Examination of fouling and slagging behaviour and consideration of aspects for gas clean-up plant design.
- Development of techniques for cane trash collection, storage and preparation
- Pressurised gas clean-up unit development. Development and proving of a clean-up unit suitable for scale-up to 5–250 MW gasification plant designs.
- Gasification reactivity studies. Characterisation of the rate of bagasse and cane trash char gasification under BIG/CC operating conditions.
- Optimisation of bagasse and cane trash pre-processing, handling and storage techniques for use in a BIG/CC power plant.
- Detailed gasification power plant design. Integration of all the research projects into a demonstration plant design.

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REFERENCES

Acaroolu, M. and Aksoy, A.S. (1998). 3rd Growing Year Results of C4 Energy Plant *Miscanthus sinens* in Producing Energy from Biomass, http://193.140.140.109/~acaroglu/wurzburg.htm.

Anon. (1998). ABB Carbon, PFBC Update, http://www.abb.se/carbon/.

Burnham, L. (1993). Renewable Energy — Sources for Fuels and Electricity, Earthscan Publications, London, 750.

Bridgwater, A.V. (1995). The technical and economic feasibility of biomass gasification for power generation, Fuel, Vol. 77, No. 5, 631–653.

Chong, Y.O., White, E.T., Rudolph, V. and Judd, M.R. (1992). Bagasse combustion in a fluidised bed. Proc. Aust. Soc. Sugar Cane Technol., 4: 326–332.

Centro De Technologia Copersucar (CTC) (1998). Project BRA/96/G31 Biomass Power Generation Sugar Cane Bagasse and Trash, Newsletter of the Centro De Technologia Copersucar, Piracicaba, Brazil.

Dixon, T.F., Hobson, P.A., Joyce, J.A., Pohl, J.H., Stanmore, B.H. and Spero, C. (1998). Electricity Cogeneration and Greenhouse Gas Abatement in the Sugar Industry, Queensland Biomass Energy Group, Mackay, Australia.

Gabra, M., Salman, H. and Kjellstrom, B. (1998). Development of a Sugar Cane Residue Feeding System for a cyclone gasifier. Biomass and Bioenergy, Vol. 15, No. 2, 151.

Harris, D.J., Wall, T.F., Beath, A.C., Patterson, J.H., Hurst, H.J., Cahill, P.H., Nixon, B.T., Prokopiuk, A.J., Novak, F. and Smith, I.W. (1996). Advanced Power Generation: Gasification Reactivity of Australian Bituminous Coals, ACARP Project C1612, Australian Coal Association Research Program, Sydney, 112.

Hobson, P.A. and Dixon, T.F. (1998). Gasification Technology; Prospects for large-scale high efficiency in the Australian sugar industry. Proc. Aust. Soc. Sugar Cane Technol., 20: 1–9.

Hurst, H.J., Chatfield, S.P., Saxby, J.D. and Patterson, J.H. (1997). Project 5058: Application of differential thermal analysis (DTA) to coal ash characterisation and ash fusion testing, Australian Coal Association Research Program, Sydney, http://www.acarp.com.au/html/b023.html.

Laughlin, K.M. and Sullivan, K.M. (1997). Project 4059: Testing of Australian coals under gasification conditions, ACARP, http://www.acarp.com.au/html/b045.html.

Miles, T.R, Miles, T.R. Jr, Baxter, L.L., Bryers, R.W., Jenkins, B.M. and Oden, L.L. (1995). Alkali Depostits found in Biomass Power Plants — A Preliminary Investigation of their extent and Nature, NREL Subcontract TZ–2–11226–1, http://www.teleport.com/~tmiles/alkali/alkali.htm.

Rao, P.J.M. (1997). Industrial Utilisation of Sugar Cane and its Co-products, P.J. International Group Consultants, New Delhi, 224–225.

Reisinger, K., Haslinger, C., Herger, M. and Hofbauer, H. (1996), Biobib — A Database for Biofuels, University of Technology, Vienna, http://edv1.vt.tuwien.ac.at/ag_hofba/biobib/biobib.htm.

Stutzman, P.E. and Centeno, L. (1995), Compositional Analysis of Beneficiated Fly Ashes, National Institute of Standards and Technology Project 5598, USA, http://flame.cfr.nist.gov/bfrlpubs/build95/art010.html.

Wiant, B., Bryan, B. and Miles, T. Jr. (1998). Hawaiian Biomass Gasification Facility: Testing Results and Current Status, Report for Westinghouse Power Generation, USA.