BAGASSE AND CANE TRASH COMBUSTION: WHERE TO NEXT?

By

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Abstract

THERE is an ever-present need to reduce the installed cost of bagasse boilers while increasing cogeneration plant efficiency. This is partnered with a push to higher steam conditions and the desire to burn opportunity fuels such as cane trash. Notwithstanding incremental advances introduced by boiler manufacturers and developers/consultants such as the Sugar Research Institute, bagasse boilers have changed little in the past 25 years. At the same time, there have been advances in combustion and cogeneration technologies for other biomass fuels, opportunity fuels such as municipal wastes, low rank coals and high rank coals. When sugar industry engineers are considering technology options for boiler upgrades and cogeneration plants, it is important that they are 'informed consumers'. Hence, this paper aims to outline some of the many combustion and cogeneration technologies with potential application in the sugar industry. This includes improvements to conventional suspension fired furnaces, alternative furnace designs, gasification, staged combustion and steam cycle upgrades. In recognition of the fact that major new installations are difficult to justify, the retrofit/integration/upgrade potential of each technology is also considered.

Introduction

In the interests of maximising investment returns from cogeneration, there is an ever-present need to reduce the installed cost of sugar industry power plants. Similarly, there is a desire to increase cogeneration plant operating hours and thus asset utilisation, by firing opportunity fuels such as cane trash. There is also a desire to provide excess bagasse for alternative uses

Issues in the combustion of cane trash and opportunity fuels

Opportunity fuels include cane trash, wood chips, green waste, agricultural wastes, sorted municipal waste and factory waste streams such as mill mud and dunder. Reliable supply of opportunity fuels is typically a problem. The ability to accept fuels from a variety of sources is a desirable feature.

Fuels with high ash contents, i.e. most opportunity fuels, can cause significant fouling and/or corrosion problems in furnaces. Darley (1993) and Tillman (1991) gave good accounts of the specific issues. Miles (1998), Jenkins *et al.* (2002) and Turn *et al.* (2002) have also provided substantial insight into the issues with regards to combustion of cane trash and other agricultural wastes, through a combination of laboratory and full scale trials. In light of the challenges presented by opportunity fuels, the key features of a suitable combustion technology are flexibility and robustness with regards to both fuel handling and combustion.

The benefits of being 'informed consumers'

Development times for industrial combustion and cogeneration technologies can be long. Stultz and Kitto (1992) reported that the first commercial installation of a coal fired supercritical steam boiler was in 1957, thirty years after initial testing commenced. Biomass gasification has undergone at least 25 years of development and is not yet commercial for medium and large scale installations. Closer to home, the SRI swirl burner combustion system underwent 13 years of development before the first commercial installation. A spin-off technology, the SRI swirl spreader, has faired much better, with six years taken to achieve the first fully commercial installation, in the Philippines in 2005.

Less than 1% of the steam boilers in the world (by capacity) are biomass boilers, of which a large proportion are bagasse boilers (WADE, 2005). By the authors' estimate, there are perhaps 4000 bagasse boilers operating globally, with 100–150 substantially renovated or replaced each year. Of this number perhaps 20–30 projects annually would be specifically classed as new cogeneration boilers. Hence, bagasse boilers represent a relative small niche market for boiler manufacturers; making it difficult to justify technology development specifically targeted at the sugar industry. Traditionally, the Australian sugar industry has played an active role in bagasse boiler technology development and has frequently pushed boiler plant manufacturers beyond their existing offerings. Arguably, technology development times have been shortened as a result. Presently, however, there is a net loss of experienced engineers from Australian sugar factories. This threatens the ability of sugar companies to continue to play an active role in technology development and to be 'informed consumers'. The risk is that investment decision making will become less informed. This may lead to stifling levels of conservatism in investment decisions, the failure to capitalise on opportunities and/or ill-informed investment in under-prepared or inappropriate technologies. Hence, this paper aims to play a small part in educating industry decision makers by presenting an overview of biomass combustion and cogeneration technologies with potential application in the sugar industry.

Progress in combustion and co-firing technologies

Notwithstanding incremental advances introduced by boiler manufacturers and organisations such as the Sugar Research Institute, bagasse boilers have changed little in the past 25 years. At the same time, there have been advances in combustion and cogeneration technologies for other biomass fuels, opportunity fuels such as municipal wastes, low rank coals and high rank coals. Some of the relevant advances are described here.

Conventional suspension fired furnaces

Various spreader stokers for suspension firing in biomass boilers have been used for decades. Recently a new design of advanced spreader has emerged for bagasse boilers, the SRI swirl spreader. A companion technology is the advanced secondary air system. The overall intention of the two technologies is to increase volumetric heat release rate and fuel burnout, thereby increasing the amount of steam that can be generated for a given furnace size/installed cost. Mann *et al.* (2004) reported the results of the first full scale installation. The two technologies are well suited to retrofitting to existing boilers to allow incremental increases in output and/or to stabilise the combustion of variable moisture fuels.

Fluidised bed boilers

Bubbling fluidised bed (BFB) and circulating fluidised bed (CFB) systems have been applied commercially to a wide range of coals, biomasses and waste fuels for decades. The technologies are most commonly applied to fuels that cannot be cost effectively grate or suspension fired and have been occasionally investigated for bagasse.

However, bagasse is readily suspension fired and does not lend itself easily to fluidisation.

Hence, the technology is best considered for opportunity fuels, as a means to reduce the need to shred, crush, pelletise or otherwise size-modify such fuels.

BFB designs can be retrofitted to existing furnaces, as described by Korhonen *et al.* (1999). CFB designs are not readily retrofitted.

Pressurised fluidised bed combustion is a commercially established variation of fluidised bed combustion for fossil fuels. The authors are not aware of any specific development impediments for biomass fuels. However, given the similarity to pressurised gasification, the economics can be expected to be similarly unfavourable for sugar industry applications.

Cyclone furnaces (Stultz and Kitto, 1992)

Babcock and Wilcox developed cyclone furnaces in the 1940s to burn fuels that contain large quantities of ash with low melting temperatures (slagging fuels). While designed for low to medium rank coals, cyclone furnaces are also frequently applied to the combustion and disposal of a wide variety of solid wastes. Fuels such wood chips, waste bark and refuse derived fuels (RDF) have been co-fired with coal for decades in some installations.

Cyclone furnaces are designed to operate at high temperatures so that ash can be tapped-off in a molten state. Figure 1 depicts the cyclone furnace concept. The main advantages of the technology are (a) far less ash finds its way into the rest of the furnace chamber and convection bank, (b) a much smaller (lower cost) furnace and grate can be used than would otherwise be required.

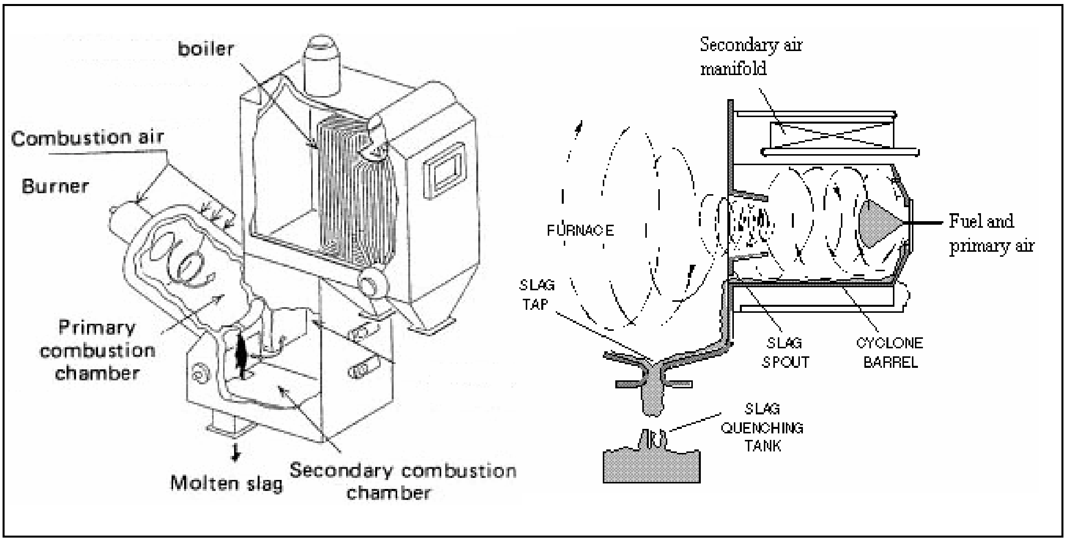

Fig. 1—Cyclone furnace concept.
Adapted from Anon. (Circa, 2000) and Staley (2005).

To achieve the desired burner operating temperature, cyclone burners require a low moisture fuel, i.e. less than 20%, which for bagasse and cane trash implies the need for fuel pre-drying. In addition, the slag properties need to be suitable for adequate slag removal. Hence, cyclone furnaces are somewhat less fuel flexible than fluidised bed or moving grate designs and must be tuned to a relatively narrow range of fuel properties.

The advantages of the molten slag from a cyclone furnace are that (a) the quenched slag is readily dewatered (b) the volume of slag is about 5% that of a dewatered ash filter cake, (b) the ash is chemically stabilised (vitrified), (c) the ash residue is not prone to dust formation (depending on the sizing method used prior to handling) and (d) the potential uses for the waste ash stream are improved.

The authors are not aware of any commercial cyclone furnaces fired by bagasse. Limited trials were undertaken in a commercial cyclone combustor in the 1980s (Williams *et al.*, 1985). It would appear that SRI's Swirl burner or Swirl spreader combustion technologies could be readily adapted to the cyclone furnace design, with due consideration of the likelihood for unburnt bagasse particles to block the slag tap. As such the technology is potentially quite suited to retrofitting, depending on site-specific space and steam circuit considerations.

Gasification

Integrated gasification combined cycle (IGCC) power plant technologies have been investigated extensively by many researchers, including the authors. The conclusion has been that IGCC will not be economically viable for the Australian sugar industry in the foreseeable future.

There are many smaller scale (<25 MW_t) commercially proven gasification technologies that may have application in the firing of opportunity fuels that cannot otherwise be handled in conventional furnaces. The economics of such technologies are unlikely to be attractive unless these can be integrated with existing electrical generating plants within sugar factories.

Staged combustion and close coupled gasification/combustion

Staged combustion is most commonly performed to manage pollutant emissions from coal and biomass furnaces (NO_x in particular). Arguably, the same concept can be used to manage ash fouling behaviours in biomass combustion, by managing the combustion temperature profile.

The cyclone furnace concept is a staged combustion approach, where the combustion process is physically separated into two different items of plant. An extension of this concept is to combust or gasify a fuel externally and then transfer the hot products into the main furnace for combustion or heat use. Clearly such a concept is well suited to retrofitting.

Staged combustion processes lend themselves to the supplementary firing of opportunity fuels, especially those that cannot be fired directly in an existing furnace. Such fuels may include dunder or mill mud, where severe erosion, corrosion and/or slagging propensity would preclude them from conventional firing.

The ability to fire opportunity fuels in a small boiler in the off-season is not only attractive for cogeneration but potentially useful for off-season refining and ethanol plant operations.

Where gasification is involved, the term close-coupled gasification/combustion is used to describe the gasification of a fuel in one section of the device followed by combustion almost immediately after in the same location or nearby. Gasification minimises the transfer of volatile corrosive ash species.

Figure 2 illustrates the concept of close-coupled gasification/combustion in a sugar factory environment.

Similar concepts have been successfully applied to the co-firing of bagasse in Thailand for over ten years and for other biomass fuels since the 1980s (Manjunath *et al.*, 2004).

Fuel drying, resizing and storage

Dry fuels can increase heat recovery from most power plants by more than 10%, primarily through a reduction in thermal losses to final flue gases. Drying poses complex engineering problems. Very few commercially available/viable options for fibrous fuels such as bagasse and cane trash exist. The same can be said for fuel resizing processes, such as shredding, pelletising and briquetting. Hence, these aspects of cogeneration technology will not be covered further in this paper.

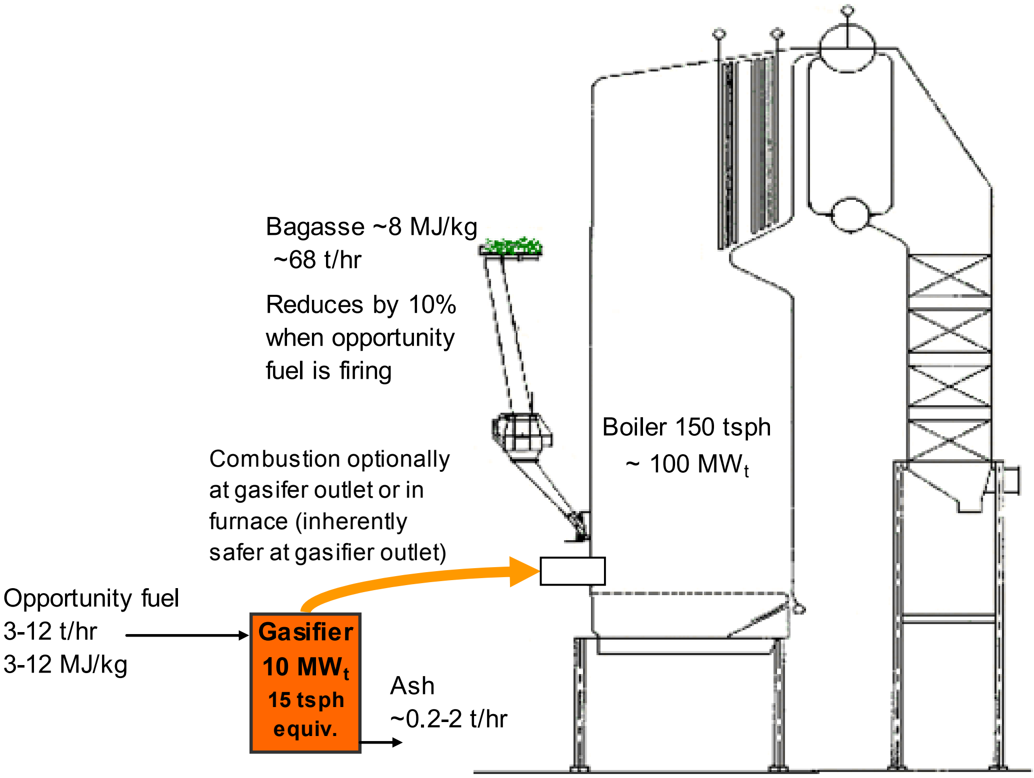

Fig. 2—Supplementary firing via close-coupled gasification/combustion retrofit.

Steam cycle technologies

Combustion is only half the story in extracting useful energy from a fuel. The other half of the story is the efficient conversion of the heat released to shaft power/electricity. The Carnot cycle defines the maximum amount of work (shaft power) recoverable from a working fluid cycled between an upper and lower temperature. This ratio of recoverable power to total energy input is defined as:

$$\eta = 1 - T_c / T_h$$

where T_C is the lowest temperature experienced by the working fluid and T_H is the highest temperature, both expressed in Kelvin. The results of applying the Carnot equation to a range of real world steam power plant operating conditions are demonstrated in Table 1.

Indicative values of real world efficiencies are also included (note: $\eta_{Typical}$ represents electricity generated relative to heat transferred to the steam) to illustrate that real world cycles rarely achieve better than 70% of the Carnot efficiency.

Table 1—Comparison of efficiencies for different power plant cycles.

	T_H	T_C	η Carnot	η Typical	% of Carnot eff.	η Fuel basis (HHV)
18 Bar sugar factory power cycle (non-condensing 100% HP steam to generator)	493 (220 °C)	388 (115 °C)	21.3%	13.5%	63%	10%
Modern sugar factory cogen. plant (non-condensing)	753 (480 °C)	398 (125 °C)	47.1%	29.5%	63%	25%
Start of the art sugar factory cogen. plant (100% condensing mode)	813 (540 °C)	311 (38 °C)	61.7%	32.0%	52%	28%
Standard utility steam cycle (black coal)	813 (540 °C)	311 (38 °C)	61.7%	42%	68%	38%
Gas turbine (High efficiency unit in open cycle mode)	1373 (1100 °C)	673 (400 °C)	51.0%	35%	69%	37%
Advanced supercritical steam cycle (black coal)	873 (600 °C)	311 (38 °C)	64.4%	47%	72%	42%
Gas turbine combined cycle (natural gas - incl. heat recovery steam cycle hence two working fluids)	1373 (1100 °C)	311 (38 °C)	77.3%	53%	69%	52%

Sources : Stultz and Kitto (1992), AGO (2005).

Figure 3 outlines the typical characteristics of alternative steam power plant designs. The choice of pressure and cycle sophistication is typically linked to power plant size and hence economics.

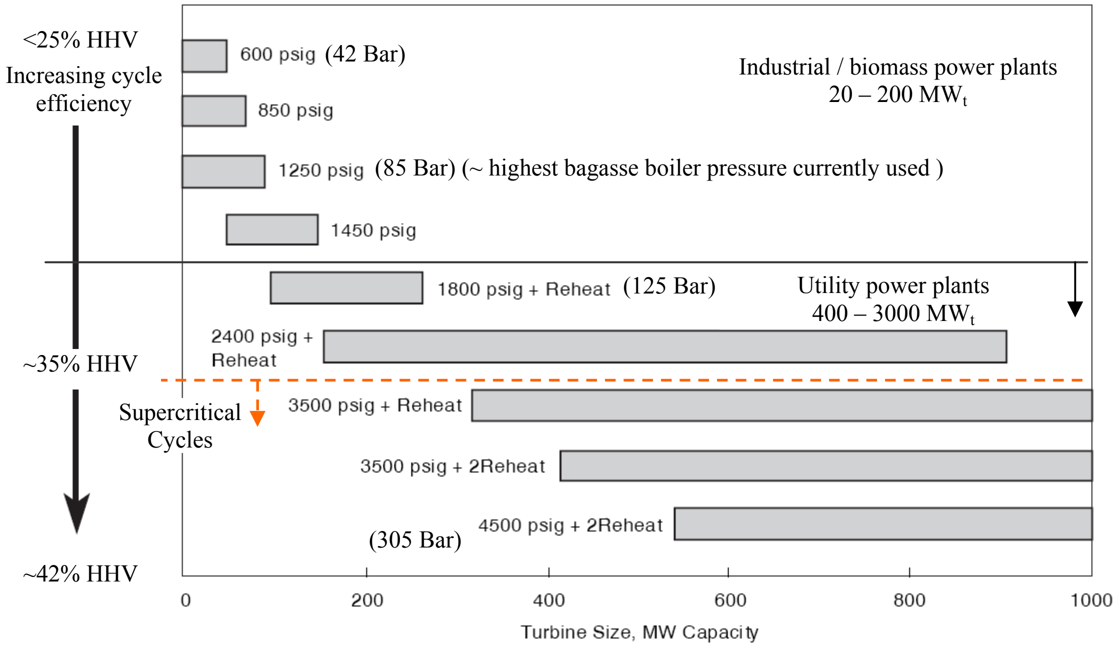

Fig. 3—Indicative characteristics of alternative steam cycles.
Adapted from Rogan (1996), with additional data from Stultz and Kitto (1992).

The key features of efficient steam power plants and their application to sugar factory cogeneration plants are discussed below.

Steam pressure and temperature

Naude (1999) outlined the efficiency benefits of higher steam pressures and temperatures. Increases in power generation as great as 150% were predicted for increasing steam temperature from 280°C to 525°C; in general agreement with the predicted increase in Carnot efficiency outlined in Table 1.

Regenerative feedwater heating

Feedwater heating raises the average temperature of the heating phase of the steam cycle which brings the cycle closer to the ideal Carnot cycle. Up to seven stages of feedwater heating are commonly used in utility power plant, for an increase of around 4 units in cycle efficiency (10%) for a condensing steam cycle (Stultz and Kitto, 1992). Naude (1999) reported similar benefits could be derived merely from a single 40°C stage of feedwater heating in a sugar factory cogeneration plant, as feedwater heating raises the average heating phase temperature proportionally more when the final steam temperature is relatively low.

Conventional sugar factory cogeneration cycles have direct contact heating in the deaerator and indirect heating in economisers, but rarely have any other significant feedwater reheating. This is due to (a) the primary benefit of feedwater heating being achieved in fully condensing power cycles and (b) the cost of feedwater heaters can be difficult to justify at scales less than 120 MW (Lowry *et al*., 2004). Bearing these factors in mind the inclusion of multi-stage feedwater heating in a new or existing cogeneration plant requires consideration of the impact on heat transfer duties within the boiler. Firstly, boiling of the feedwater in the heating stages (including economisers) must be avoided. Higher operating pressures increase the scope for feedwater heating by raising the boiling point. Secondly, higher temperatures in the water circuit may significantly reduce the amount of heat removed in the furnace, thereby increasing the furnace exit temperature, potentially to the point that fouling of superheaters and other heat exchange surfaces could become excessive.

In utility power plants, regenerative feedwater heating is achieved by extracting steam and/or condensed moisture from various stages of the steam turbine and passing through multiple counter current heat exchange stages. Heating stages are placed both before and after the feedwater pump. Multiple extractions from the turbine may not be economically feasible in smaller sugar factory cogeneration plants.

Steam reheat

If steam is generated at sufficient pressure an opportunity arises to expand the steam through turbine stages more than once, by intermediate reheating of moist steam.

In the sugar factory context, reheat of surplus (saturated) LP steam and even surplus evaporator vapours could be implemented to allow utilisation in the low pressure stage of a condensing turbine. The cost of running low pressure steam mains would make this option very sensitive to site-specific factors (e.g. distance from suitable location in existing LP or vapour lines to the boiler house).

High pressure water/steam circuit retrofits

The cost of retrofitting an existing boiler to operate at significantly higher steam pressures is generally prohibitive. Superheater uprating for higher steam temperatures has more potential. However, it may be possible to add an additional water circuit. One possible retrofit concept is outlined in Figure 4. This is a single pass circuit possibly implemented in a furnace platen configuration, with an external steam separator that discharges captured moisture from the saturated steam stage and flashes this en-route to the existing lower pressure steam or mud drums. Superheating is then completed in a second tube bank. The quantity of 15 tonnes of steam per hour in the example matches to the 10 MW_t opportunity fuel firing system described earlier and is also appropriate to the operation of a moderately sized steam efficient distillery in the off-season.

Obviously each water/circuit retrofit needs to be considered on a case-by-case basis with regards to the effects on furnace performance, boiler support structural issues etc. It is important to determine the turbine options first, as the steam circuit design pressure, temperature, flow and load characteristics must be closely matched to the chosen turbine.

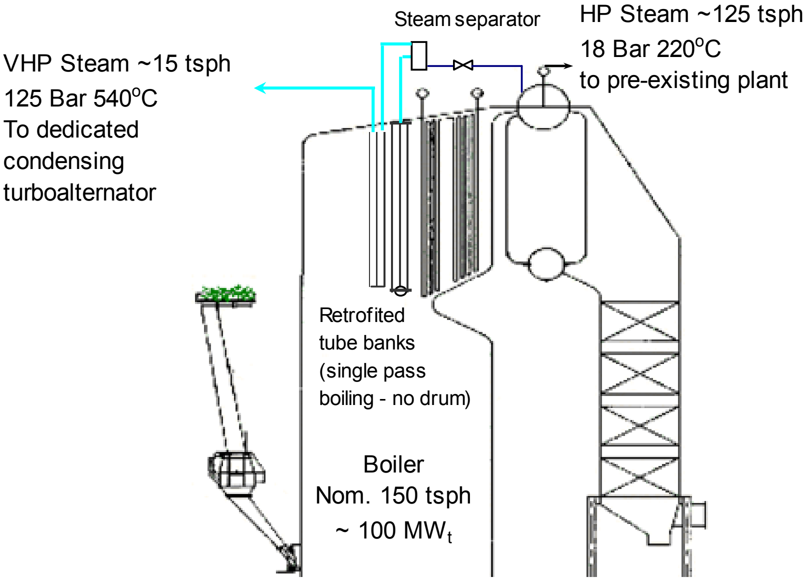

Fig. 4—Concept of high pressure steam circuit retrofit to an existing boiler.

Other power cycles

There are a host of other power cycles proposed or under development for biomass and fossil fuels, including indirect fired (hot air) turbines, molten metal processes, organic Rankine cycles, the Kalina cycle (water/ammonia working fluid). In most cases, the working fluid is not as simple to handle as water/steam so the plants are comparatively expensive. Such technologies are unlikely to be viable for sugar industry applications in the foreseeable future.

Conclusions

Table 2 summarises the combustion and cogeneration cycle alternatives discussed in terms of key benefits, issues, technology status and retrofit potential.

All of the technology options described in this paper can be readily modelled and evaluated with modern process modelling software. In most cases this must be performed on a site-specific basis.

Suggested further reading

This paper has only briefly touched on some technology options, their features and the potential issues for sugar industry applications. For those who wish to become better informed, the following reference books and internet resources are recommended:

- www.spiraxsarco.com/learn/ and www.cip.ukcentre.com/steam.htm Excellent resources for novice steam plant engineers and those who need to brush up on certain aspects.

Table 2—Summary of technologies with potential use in sugar industry cogeneration plants

Technology	Benefits and issues	Commercial status	Retrofit potential
SRI Swirl spreaders/ advanced secondary air system	Improved furnace stability and heat release rate. Reduces plant capital cost.	First commercial installation of swirl spreaders complete.	Good potential.
Fluidised bed combustion	Not all fuels have suitable properties for fluidisation. Potentially expensive to implement relative to conventional bagasse furnaces.	Commercialised for a wide variety of fuels. Not commercialised for bagasse / cane trash.	BFB types can be retrofitted. CFB types not readily retrofitable. Pressurised systems cannot be retrofitted.
Cyclone furnace	Allows firing of high ash fuels with low ash melting temperatures in relatively small furnace volumes.	Commercially used for decades with a variety of fuel, but not bagasse / cane trash.	Generally good retrofit potential but very site dependent.
Full scale integrated gasification	High thermal efficiency. Negligible particulate emissions. Materials handling, gas cleanup are main issues with regards to bagasse / cane trash. High capital costs per MW and very large project sizes.	Number of technologies technically proven with some biomass fuels. Some commercial for certain coals. None commercially viable for bagasse cogeneration at present.	Not retrofitable.
Staged gasification/ combustion with venting of hot flue gas to an existing boiler furnace	Provides the means to segregate the combustion of fuels with very different handling and ash properties to the primary fuel supply.	Existing commercial technologies not proven at outputs greater than 5 MWt	Good retrofit potential. With opportunity fuels can operate in off-season.
High pressure/temperature steam circuit retrofits	Increased steam cogeneration plant efficiency. Ability to implement FW reheating and steam reheat specifically into cogeneration steam circuit.	Basic technology fully commercial. Retrofit concept commercially novel.	Can be implemented to minimise impact on existing steam systems. Only useful for retrofit when a suitable turbine can be sourced.
Other cycles	Improved cogeneration plant efficiency.	Under development outside of sugar industry.	Possibly some potential for retrofit but generally will require mostly new plant.

- Steam – Its generation and use, by Stultz and Kitto (1992) of Babcock and Wilcox Ltd. and the Babcock and Wilcox website www.babcock.com The book is a thorough technical reference and arguably the bible of steam generation. The website contains many technical papers relating to a wide range of current commercial combustion and steam cycle technologies as well as case studies.

- The combustion of solid fuels and wastes by Tillman (1991). A straightforward text that provides good coverage of theory and practice in solid fuel and solid waste combustion.
- www.ieabioenergy.com The international energy agency bioenergy research website. A good source of status information with regards to the development of biomass thermal utilisation technologies.
- www.bioenergyaustralia.org The Australian biomass taskforce website. A good source of current information with regards to biomass technology activities in Australia.
- Pyrolysis and gasification of Biomass and waste by Bridgwater (2003). This book gives a good indication of the current directions in technology development and plant economics but is not for novice readers. Progress reports on the commercialisation of a host of different technologies are provided.
- www.juniper.co.uk/index.html Website of Juniper Consultancy Services of the UK, a provider of detailed market and technology surveys in the fields of combustion and gasification technologies.

REFERENCES

AGO Generator Efficiency Standards – Question & Answers 11/08/2005, Australian Greenhouse Office, Department of the Environment and Heritage. 8/12/2005. http://www.greenhouse.gov.au/ges/qa.html

Anon. Cyclone Smelting Furnace Circa 2000, Global Environment Centre Foundation. 9/12/2005. http://nett21.gec.jp/JSIM_DATA/WASTE/WASTE_5/html/Doc_509_2.html

Bridgwater, A.V. (2003). Pyrolysis and gasification of biomass and waste : proceedings of an expert meeting : Strasbourg, France, 30 September - 1 October 2002. Newbury, University of Aston in Birmingham Bio-Energy Research Group, CPL.

Darley, P.C. (1993). Steam generation in waste incineration plants. Cost effective steam and power generation by the combustion of waste, London, Mechanical Engineering Publications Ltd.: 10 p.

Jenkins, B.M., Thy, P., Turn, S.Q. *et al.* (2002). Composition and microstructure of ash deposits from co-firing biomass and coal. Bioenergy 2002 – The tenth biennial bioenergy conference, Boise, Idaho, USA, Pacific regional biomass energy program.

Korhonen, S., Jacobson, T., Jäskeläinen, K. and Hulkonen, S. (1999). Bubbling Fluidised Bed Retrofit with Modern Design Tools. 15th International Conference on Fluidised Bed Combustion, Savannah, Georgia, ASME: 14 p.

Lowry, G., Gamble, G., Riggs, A. and Tatong, S. (2004). Biomass Power – How Mitr Pohl Sugar and Alstom made it happen. Proc. Aust. Soc. Sugar Cane Technol., 26: CD-ROM.

Manjunath, D.A., Cotton, J., Ekamabaram, A., Sellakumar, K.M. and Palonen, J. (2004). Efficient and Clean Biomass Gasification and Combustion Technologies for Bagasse Circa 2000, Foster Wheeler. 15/08/2004.

http://www.fwc.com/publications/tech_papers/powgen/bagasse3.cfm

Mann, A.P., Stoneham, T., Wesener, M. *et al.* (2004). Operation, Testing and modeling of the advanced swirl spreader and secondary air system installation at Proserpine mill. Proc. Aust. Soc. Sugar Cane Technol., 26: CD-ROM).

Miles, T.J. (1998). Alkali Deposits found in Biomass power plants: A preliminary investigation of their extent and nature. National Renewable Energy Laboratory. Portland, USA, National Renewable Energy Laboratory.

Naude, D.P. (1999). The application of all year power generation for the cane sugar industry with particular reference to steam plant design. Proc. Aust. Soc. Sugar Cane Technol., 21: 419–425.

Rogan, J.B. (1996). Comparison of Current Technology Options for Power Generation in North America. Global Climate Change Forum, Columbus, Ohio, USA, Public Utilities Commission of Ohio.

Staley, L. (2005). Babcock and Wilcox Co. Cyclone Furnace – Technology Description U.S. EPA, National Risk Management Research Laboratory. 10/12/05. http://clu-in.org/products/site/complete/democomp/babcock.htm

Stultz, S.C. and Kitto, J.B. Ed. (1992). Steam – Its generation and use. Barberton, Ohio, USA, The Babcock and Wilcox Company.

Tillman, D.A. (1991). The combustion of solid fuels and wastes. San Diego, Academic Press, Inc.

Turn, S.Q., Keffer, V. and Staackmann, M. (2002). Analysis of Hawaii Biomass Energy Resources for Distributed Energy Applications. Maui, University of Hawaii, Hawaii Natural Energy Institute, School of Ocean and Earth Sciences and Technology.

WADE (2005). World Survey of Decentralised Energy 2005. Edinburgh, World Alliance for Decentralised Energy: 45 p. www.localpower.org

Williams, E.G., Crawford,W.B. and Fairbairn,W.R.F. (1985). Cyclonic Combustor Developments. Proc. Aust. Soc. Sugar Cane Technol., 7: 299–306.