BIGCC system for New Zealand: an overview and perspective

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Abstract

The system of biomass integrated gasification combined cycle (BIGCC) has been selected for technology transfer to New Zealand to generate electricity and thermal energy using wood residues. This is due to its advantages of higher electrical efficiency, lower emissions and more flexible ratio of electricity to thermal energy. However, the technology needs to be further developed and improved for commercialisation. This paper reviews and evaluates five BIGCC demonstration projects and a steam gasification project developed overseas to learn their experiences and lessons. A BIGCC system with steam gasification is recommended for technology transfer to New Zealand. The key areas for further research and development are identified to be optimisation of the gasification performance, improvement of gas cleaning technology, optimisation of the system integration, and reduction of capital cost.

Introduction

In 2004, the total New Zealand primary energy supply was 766 PJ and 69% of this was from oil, gas and coal (MED, 2005). With predicted declining gas reserves in New Zealand and price increases for imported oil, seeking alternative and sustainable energy resources is becoming an urgent issue. Among the most affected is the forestry and wood processing industry. In the latest survey of 2002, the wood processing sector consumed 9% of the national primary energy supply and purchased approximately 12.7 PJ electricity and 20 PJ energy in the form of oil, gas, coal and geothermal (Gifford and Anderson, 2003). On the other hand, the industry generates abundant wood residues both in wood processing and forestry (Robertson and Manley, 2006; Li *et al*., 2006) that can be used as a renewable energy resource.

In order to utilise the wood residue resource more efficiently and economically, a research programme led by the Wood Technology Research Centre, University of Canterbury, has been undertaken to develop woody biomass integrated gasification combined cycle (BIGCC) system for New Zealand. The target of this programme is to achieve a step change increase in heat and power generation from self-generated biomass in the wood processing industry. The programme consists of four objectives including evaluation of BIGCC technologies developed overseas; transfer and development of a BIGCC system to suit NZ conditions; mapping of woody biomass feedstock supply and energy demand; and design and modelling of woody BIGCC systems.

The study presented in this paper evaluates the BIGCC demonstration projects developed overseas so we can learn their experiences and lessons. From this study, a potential biomass gasification system is recommended; and areas for further R&D are identified.

In a BIGCC system, biomass is thermally gasified in an oxygen deficient environment to produce a producer gas containing hydrogen, carbon monoxide, carbon dioxide, methane, and nitrogen with calorific value of 4-18 MJ/Nm3 depending on gasification medium (Brown *et al*., 2006). In addition, the producer gas also contains tar, particulates, alkalis and compounds of nitrogen and sulfur which need to be cleaned out for combustion in a gas engine or gas turbine for generation of electricity, which is called the Joule cycle. The hot exhaust gas from the gas engine or gas turbine then goes through a heat recovery steam generator (HRSG) to raise steam for a steam turbine generating additional electricity and this is known as Rankine cycle (Williams and Larson, 1996). The exhaust gas discharged from the HRSG can be further used for drying biomass feedstock or for supplying heat to other processing operations.

In comparison with conventional combustion of biomass and other gasification systems, the BIGCC system has advantages of high and flexible power-to-heat ratio, high electrical efficiency up to 48% (Rankine 29%), low electricity production cost (at over 15MWe scale) and low emissions (Bridgwater, 1995).

The integrated gasification combined cycle (IGCC) process was initially developed in coal gasification for high efficiency power generation. Coal has a high calorific value (CV) of 26-37 MJ/kg (od, oven dry base) and the commercial coal power stations are normally at large scales, up to 1000 MWe. Most modern coal IGCC systems operate at high pressures (20 bar or higher) and high temperature (above 1000°C) using oxygen-blown gasifiers (Higman and van der Burgt, 2003). The large scale of coal power stations is a key factor to their commercial success.

The IGCC for biomass (BIGCC) has been tested since the 1990s. However, compared to coal, biomass has different physical and thermodynamic characteristics and its resource is more scattered, thus it is difficult to build a large scale plant. The biomass has lower bulk density, lower CV (16-19 MJ/kg od), higher reactivity, lower ash melting point, and higher tar formation at its lower gasification temperature. As BIGCC plants are likely to be small to medium scale (up to 100 MWe), further studies are needed to optimise the system and to reduce costs by modification of the coal IGCC system.

BIGCC Systems developed overseas

In the last decade, there has been significant global interest in building demonstration plants for the BIGCC system. The European Union (EU) set up a THERMIE programme in 1993 to provide financial support for the

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demonstration of the technical and economic feasibility of biomass gasification using the BIGCC concept and feedstock from short rotation coppice (SRC). The capacity of the demonstration plants was in the range of 8-12 MWe electricity output. Three projects were selected and funded in 1994 by the programme including ARable Biomass Renewable Energy (ARBRE) in UK, Energy Farm (EF) in Italy and Biocycle in Denmark (Morris and Waldheim 2002). The Biocycle project, however, was stopped at an early stage due to the difficulty of finding a suitable customer and a sufficient amount of reasonably priced biomass (Salo 1998). Meanwhile, other technology developers also tried to demonstrate the BIGCC technology either based on an existing gasification facility such as the Chianti project in Italy (Barducci *et al* 1997) or based on a stand-alone project such as the Värnamo project in Sweden (Ståhl and Neergaad 1998) and the Andhra Pradesh project in India (Patel and Salo 2004).

More details of the above five projects are given in Table 1 in which a newly developed steam gasification plant in Güssing, Austria (Hofbauer *et al.* 2002), is also included for its potential use in a BIGCC system. As can be seen, Europe has been the most active region in promoting the BIGCC system for bioenergy generation. According to the gasification conditions, the systems in Table 1 can be classified as atmospheric air gasification (ABIGCC), pressurised air gasification (PBIGCC) or steam gasification.

Table 1: BIGCC demonstration projects overseas.

Project	Technology	Capacity	Status
ARBRE, UK	ABIGCC, Termiska Processer AB (TPS)	8 MWe	Bankrupt in 2002, owner changed, uncertain from 2003
EF, Bioelettrica, Italy	ABIGCC first, Lurgi PBIGCC later, Carbona	12 MWe	Cancelled 2003
Chianti, Italy	ABIGCC concept, TPS	7.7 MWe 18 MWth	No further information
Värnamo, Sweden	PBIGCC, Foster Wheeler	6 MWe 9 MWth	Was in operation for 3600 hr ended 1999 Recently changed the goals of the project
Andhra Pradesh, India	PBIGCC, Carbona	12.5 MWe	Operation planned in 2006
Güssing, Austria (not BIGCC)	Steam gasification combined with an engine, Vienna University of Technology	2 MWe 4.5 MWth	In operation since 2002

Each project listed in Table 1 has unique characteristics although the BIGCC systems have common components of gasification, gas cleanup, and Joule cycle combined with Rankin cycle. The ARBRE plant was based on the atmospheric circulating fluidised bed (CFB) gasification process developed by TPS of Sweden (Pitcher *et al.* 1998). It was a complete BIGCC system coupling the gasifier with a gas turbine, a steam turbine and fuel drying (Morris and Waldheim 2002). It used a hot gas catalyst for tar cracker and water was used for the cool gas scrubbing which was treated for irrigation of the short rotation coppice. Unfortunately, due to changes of the project owners and contract amendments, the project was stopped after the producer gas first routed to the burner of the HRSG.

The EF project owned by Bioelettrica had completed the plant design, equipment selection and economic evaluation based on atmospheric gasification developed by Lurgi (Germany) in May 1997. The construction at the chosen site, close to Pisa, was not able to start as planned due to the difficulty in obtaining a consent (De Lange and Barbucci 1999). Then the project design was changed from atmospheric gasification to pressurised gasification developed by Carbona (Scoditti 2002) and it was then reported that the project was cancelled (Kwant and Knoef 2004).

In Chianti, TPS provided the design of the atmospheric CFB gasifier in commercial scale coupling with an engine for power generation. After commissioning in 1992, the plant was handed over to the owner, Servizi Ambientali Area Fiarentina early in 1993 (Granatstein 2003). With the experience of the commercial plant, Barducci *et al.* (1997) proposed a modification of the existing system to a BIGCC with the Joule cycle and Rankine cycle in parallel rather than sequential. However, there is no report that the proposal was ever realised.

The Värnamo project was owned by the joint venture Bioflo Ltd consisting of the technology developer Foster Wheeler Energy International Inc (USA) and Sydkraft AB (Sweden) (Ståhl *et al.* 1997). The system used a pressurised CFB gasifier and hot gas filter. Started in 1993, the plant had been in gasification operation for more than 8,500 hr (about 1 year) and the gas turbine had run on producer gas for more than 3,600 hr by the end of 1999 (Rensfelt 2002b). With the conclusion that the technology was proven to be successful for the demonstration, the facility is being modified for research on syngas production by the sixth EU framework programme (Kwant and Knoef 2004).

The Andhra Pradesh plant will consist of a Carbona high pressure bubbling fluidised bed (BFB) gasifier, Pall filters and a combined cycle power plant that includes two Alstom Typhoon gas turbines, one HRSG and a condensing steam turbine. Toyo Engineering India Ltd will be the engineering, procurement and construction contractor, and the operation and maintenance contractor for the project. Carbona will provide support for gasification plant with construction supervision, commissioning, start-up supervision and training. The project has been in progress and the operation was planned to begin in 2006 (Patel and Salo 2004).

The Güssing plant is a combined power and heat (CPH) system using a gas engine without the combination of steam turbine. Its internal CFB gasifier has dual fluid beds that separate the gasification from the combustion. Using steam as the gasification medium, the gasification produces a gas with a calorific value of 10-18 MJ/Nm^3 compared to 4-7 MJ/Nm^3 for the air-blown gasification. The process does not generate waste water as an esterified rapeseed oil is used as the scrubbing solvent and is burnt in the combustion zone of the gasifier (Hofbauer *et al.* 2002). The project had been in operation successfully for 9792 hr with the gasifier and 7100 hr with the gas engine by March 2004 (Rauch *et al.* 2004). It is still in operation now although it is being used for liquid fuel research. More details on the gasification system used in the Güssing plant can be found in the paper of Brown *et al*. (2006).

Evaluation of the BIGCC Systems

The evaluation purposes are to examine the common and unique features of the BIGCC systems, to address their performance advantages and disadvantages, and to compare their conversion efficiencies and capital costs. A unique feature in the BIGCC demonstration projects is the fluidised bed (FB) gasifier, either as CFB or BFB. The FB gasifier can achieve uniform temperature distribution throughout the bed and has potential to be used for large scale. It can also handle various biomass feedstocks, has high conversion efficiency and generates producer gas with constant calorific value. In contrast, fixed bed gasifiers and entrained flow gasifiers have the limits in these areas (Higman and van der Burgt, 2003; Bridgwater, 1995) for a BIGCC system.

Another common feature for the BIGCC demonstration projects is the use of air as the gasification agent resulting in the producer gas having a low CV, typically 4-7 MJ/Nm^3. The expensive production of oxygen makes the oxygen-blown gasification preferred only in large scale plants for coal gasification (Higman and van der Burgt 2003). In air-blown gasification, the dilution of nitrogen in the producer gas not only increases the cost of energy recovery and gas cleanup, but also requires modification of the gas turbine. To avoid these problems, steam gasification, as used in the Güssing plant, is seen to have similar advantages as the oxygen gasification but the steam gasification is much cheaper. Steam gasification also has the most reliable biomass feed, ash handling and gas cleaning systems similar to that of the atmospheric system (Belgiorno *et al.* 2003).

Atmospheric gasification as used in the projects of ARBRE, EF, and Chianti is reliable in operation and gas clean-up. It has simple biomass feeding and ash handling systems, and the technology is relatively mature. The gasifier and turbine can operate independently so the system is more flexible. However, in such a system, some energy is consumed to compress the producer gas for the gas turbine, and the turbine feed gas needs to be very clean for the compressor. Therefore the system has a lower total net efficiency (Bridgwater, 1995). In addition, tar removal by scrubbing needs improvement to optimise the operation time and minimise or eliminate the generation of waste water.

In pressurised gasification, the pressure is generally selected in accordance with the requirements of the downstream process operations such as a gas turbine which typically requires a pressure of 20-40 bar. The pressure is usually achieved by pressurising the feedstock to the gasifier, and thus there is no need to further compress the producer gas for turbine. Also the producer gas can be cleaned up in hot conditions. Pressurised gasification has advantages of high overall efficiency gained from savings of gas compression, internal energy of tar as relatively high tar content is accepted in the gas turbine, and enthalpy of the hot producer gas. However, the system is more complicated and has higher capital cost. For the system to be economically feasible, the plant needs to be over 50MWe (Bridgwater, 1995). Other disadvantages for the pressurised system include that inert gas is required to transport the feedstock and hot gas cleanup technology needs improvement for long time operation.

Gas cleanup technology varies with the gasification technology chosen. Tar management still remains the main technical barrier for commercialisation of the BIGCC (Maniatis 2001). Atmospheric gasification requires a cleaning system usually consisting of a tar cracker, gas cooler, bag house filter and wet scrubber. The waste water from the wet scrubber needs to be treated before it is discharged. Pressurised gasification uses a metallic candle filter for hot gas cleaning without generating waste water. Steam gasification with an appropriate bed material acting as a catalyst produces a gas with low tar content and requires a gas cleaning system similar to the atmospheric gasification but no need of any additional tar cracker (Hofbauer *et al* .2002).

In a BIGCC system, electricity is generated from two sources: a gas turbine and a steam turbine. The utilisation of a gas turbine for the low CV gas still requires some modification. Compared to gas turbines, gas engines have higher tolerance for gas contaminants, but a lower efficiency in the combined cycle (Bridgwater 1995). The gas engine is normally relatively small scale so a large scale plant needs more engines which compromise the economic benefit. HRSG and steam turbines are relatively mature technology, but the system cost is dependent on the system scale (Williams and Larson 1996) which is a key area for reduction of the capital cost.

Table 2 lists the energy conversion efficiency and capital cost of the demonstration projects reviewed above. As can be seen, only Värnamo and Güssing plants have been running for a long period of time and have verified the conversion efficiency. The efficiencies in other plants are projected values that have not yet been proved. All of the projected and verified electricity conversion efficiencies are lower than the potential maximum efficiency of 48% reported by Bridgwater (1995) due to the scale being smaller than the optimum. The low electricity conversion efficiency of the Güssing plant is also a result of the lack of integration with a steam turbine cycle. Therefore, it is certain the efficiency will be increased when the steam turbine cycle is included. Another interesting observation is that there is no noticeable difference in the electricity conversion efficiency between the atmospheric (ABIGCC) and the pressurised gasification system (PBIGCC).

The specific capital cost per kW electricity ranged from NZ$5,268/kWe (EF) to NZ$10,296/kWe (ARBRE) (as at March 2004), which are similar to that reported for the first BIGCC plants at similar scales by Bridgwater (1995). The cost of Värnamo plant should be much higher than $2,280/kWe that was estimated for a 60MWe plant with mature technology (Rendfelt 2002b). However, the specific capital costs reviewed do not show any consistent trend as a function of plant scale. There is no detailed cost analysis available for any of these demonstration plants. A cost analysis for a proposed ABIGCC plant of 10 MWe by Bridgwater (1995) indicated the combined cycle is the most expensive unit and costs 43% of the total investment.

Table 2: Energy conversion efficiency and investment cost of the BIGCC projects.

System	ABIGCC			PBIGCC		SteamG
Plant	ARBRE	EF	Chianti	Värnamo	India	Güssing
Electric efficiency, %	29 (projected)	33 (projected)	39 (projected)	32 (actual)	37 (projected)	25 (actual)
Thermal efficiency, %	-	32	-	51	-	56.3
Capital cost, NZ$/kWe	10,296	5,268	8,140	>>2,280	-	9,160
Electricity price, $NZ/kWe					0.15	0.23
Reference	Rensfelt 2002a	De Lange & Barbucci 1999	Granatstein 2003	Rensfelt 2002b	RR Bio 2004	Hofbauer *et al* 2002

The HRSG in the Rankin cycle contributes to this cost significantly. The second most expensive unit is the gasification accounting for 26% followed by the feedstock preparation unit accounting for 15%. Reduction of the capital cost of the power generation facility is critical in reducing the capital cost of the BIGCC system.

The electricity price is only an indication for the Güssing plant since the thermal energy price is not included and the price for the India plant is only a projected value.

Experiences and lessons

BIGCC systems are still in the development stage. Only the Värnamo project proved its technology before changing the research direction and the India project is still in construction. The remaining three demonstration projects reviewed did not achieve the expected outcomes. The reasons for the lack of success are complex and vary with the projects, however, there are some common reasons such as financial shortages in project execution and unrealistic profit expectations from the demonstration operation. General experiences and lessons have been identified as follows.

The first factor for success is to conduct a detailed feasibility study before a project is designed and constructed to identify the biomass availability, energy market, economic plant scale, feasible generation system, significant cost units and improvement areas. Therefore, in order to build a full scale commercial biomass energy plant, plant location and scale are critically important. This is related to the availability and costs of the biomass feedstocks. In addition, the system complexity and level of integration need to be based on the scale and energy requirements of the end users of the thermal energy produced.

The second factor is unrealistic expectations and the fact it was not realised in the planning stage that the demonstration projects were not at the economically optimised scale for profitability but the projects' focus was to validate the technology, to identify technical problems and to gain first hand information for later scale up. The next factor is the lack of logical planning. Three BIGCC demonstration projects were funded by the EU's THERMIE programme at the same time in 1994 using the similar technology. The limited fund was divided into three parts, which enabled EF and Biocycle to conduct feasibility studies and ARBRE to build the plant without completing the demonstration. A further factor for ARBRE was the unsuccessful turnkey contract to a third party, which was not the technology developer thus the management of the engineering construction and commissioning caused some delays and induced additional costs.

BIGCC for New Zealand.

In New Zealand, all of the existing biomass energy plants are based on combustion technology at small scale of less than 10 MW and the feedstock is from the sites' main business wood processing plants or pulp and paper mills. In these cases, the low conversion efficiency is not critical for the biomass energy generation. The BIGCC system which is being adopted and developed in our programme is to provide an alternative technology for more efficient generation of energy from biomass. The optimum electricity output in a commercial plant is likely to be in a medium range of 10-20MWe. However, this will be verified in the feasibility study conducted in this research programme by developing an integrated simulation model for the BIGCC system (Rutherford and Williamson, 2006). The model also incorporates the information on the gasification technology (Brown *et al.* 2006), the biomass availability and cost (Robertson and Manley, 2006), and the energy demand in a wood processing plant (Li *et al.*, 2006).

Gasification is the key unit operation which will affect the choice of other equipment in a BIGCC system. According to the evaluation, steam gasification is considered to be the most suitable technology for a medium scale bioenergy plant in New Zealand. An illustration of the proposed BIGCC system using steam gasification can be found from the paper of Rutherford and Williamson (2006). The system has a number of advantages as follows:

- Producer gas has medium heating value (10-18 MJ/Nm3) compared to 4-7 MJ/Nm3 in normal air-blown gasification. Therefore, gas turbines developed for coal gasification can be used with minimum modification.
- When using the Fast Internal Circulating Fluidised Bed (FICFB) Gasifier as tested in this programme (Brown *et*

al. 2006), high temperature combustion gas is produced in the circulating fluidised bed column which can be mixed with the lower exhaust gas from the gas engine. Therefore, gas engines can be used in the BIGCC system and compression of producer gas is not needed.
- Producer gas has lower tar content by using bed material as a catalyst thus the cost of energy recovery and gas cleanup can be reduced.
- Steam used in the gasification can be generated within the system using exhaust heat, which is either from the steam turbine or from the HRSG.

In order to apply the BIGCC technology successfully in New Zealand, some non-technical issues also need to be considered which include selection of customers and locations, gaining construction consent, and Government subsidy in construction of a demonstration plant.

Based on the evaluation and analysis of the existing technologies overseas and on our own research progresses as reported in the other papers in the same issue of this journal, further research has been planned in this programme as follows:
- Optimisation of gasification conditions such as temperature, ratio of steam to biomass, and bed material for radiata pine residues to produce a producer gas with less tar content.
- Development of gas cleanup technology to balance the gas engine or gas turbine life for economic benefit.
- Selection of gas turbine or engine for high electrical efficiency.
- Specification of biomass feedstock in terms of particle size distribution and moisture content for more efficient conversion.
- Optimisation of the system integration to achieve the highest conversion efficiency and the lowest operation cost.

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References

Barducci, G.L.; Ulivieri, P.; Polzinetti, G.C.; Donati, A.; Repetto, F. 1997: New developments in biomass utilisation for electricity and low energy gas production, on the gasification plant of Greve in Chianti - Florence, development in exploitation of LEG from BF and RDF. In A.V.Bridgwater and D.G.B. Boocock (Ed) Developments in *Thermachemical Biomass Conversion*, Vol 2 p1045-1057. Blackie Academic & Professional.

Belgiorno, A; De Feo, G; Della Rocca, C; Napoli, R.M.A. 2003: Energy from gasification of solid wastes. *Waste Management* 23: 1-15.

Bridgwater, A.V. 1995: The technical and economic feasibility of biomass gasification for power generation. *Fuel* Vol. 74, No. 5:631-653.

Brown, J.W.; Dobbs, R.M.; Devenish, S; Gilmour, I.A. 2006: Biomass gasification in a 100kW fast internal circulating fluidised bed gasifier. *NZ Journal of Forestry*, Page ?? this issue.

De Lange, H.L., Barbucci, P. 1999: The THERMIE Energy Farm Project. *Renewable Energy* 16: 1004-1006.

Gifford, J.; Anderson, C.J. 2003: Energy use in the New Zealand wood processing industry. www.eeca.govt.nz/renewable-energy/bioenergy/biomass.html visited on 16 May 2006.

Granatstein, D.L. 2003: Case study on waste-fuelled gasification project, Greve in Chianti, Italy. For IEA Bioenergy Agreement - Task 36, June 2003. www.gastechnology.org/iea August 2004.

Higman, C.; van der Burgt, M. 2003: *Gasification*. Gulf Professional Publishing.

Hofbauer, H.; Rauch, R.; Bosch, K.; Loch, R.; Aichernig, C. 2002: Biomass CHP plant Güssing- a success story. Presented at the Pyrolysis and Gasificaiton of Biomass and Waste Expert Meeting, Strasbourg, October 2002.

Kwant, K.W.; Knoef, H. 2004: Status of gasification in countries participating in the IEA & GasNet activity, September 2004.

Li, J; McCurdy, M; Pang, S. 2006: Energy demand in wood processing plants. *NZ Journal of Forestry*, this issue.

Maniatis, K. 2001: Progress in biomass gasification: an overview. In A.V.Bridgwater (Ed) Progress in *Thermochemical Biomass Conversion*, Vol 1 p1-31. Blackwell Science Ltd.

MED (Ministry of Economic Development, New Zealand). 2005. New Zealand Energy Data File. http://www.med.govt.nz/upload/28668/200507.pdf, July 2005.

Morris, M.; Waldheim, L. 2002: Update on Project ARBRE, UK - A wood-fuelled combined-cycle demonstration plant.

Patel, J.; Salo, K. 2004: Demonstration of new gasification technology. In Proceedings of the Second World Biomass Conference, Biomass for Energy, Industry and Climate Protection held in Rome, Italy, 10-14 May 2004. Vol. 1 p44-47.

Pitcher, K.; Hilton, B.; Lundberg, H. 1998: The ARBRE project: Progress achieved. *Biomass and Bioenergy* Vol.15, No.3 p213-218.

Rauch, R.; Hofbauer, H.; Bosch, K.; Siefert, I.; Aichernig, C.; ect. 2004: Steam gasification of biomass at CHP plant Guessing - Status of the demonstration plant. In Proceedings of the Second World Biomass Conference, Biomass for Energy, Industry and Climate Protection held in Rome, Italy, 10-14 May 2004. Vol. 1 p1687-1690.

Rensfelt, E. 2002a: Large scale gasification overview. Expert workshop, 30 September 2002 www.ienica.

net/usefulreports/pyrolysis4.pdf , 26 July 2004.

Rensfelt, E. 2002b: Gasification survey country: Sweden. In Kwant, K.W and Knoef, H. (Ed): Status of gasification in countries participating in the IEA & GasNet activity, September 2002. www.gastechnology.org/iea 20 July 2004.

Robertson, K.; Manley, B. 2006: Estimation of the availability and cost of supplying biomass for bioenergy in Canterbury. *NZ Journal of Forestry*, this issue.

RR Bio Energies Ltd. 2004: Biomass to Energy in Rural India. http://wire0.ises.org/wire/exchanges/Projects.nsf 1 September 2004.

Rutherford, J.P.; Williamson, C.J. 2006: Integrating advanced biomass gasifiers into the New Zealand wood industry. *NZ Journal of Forestry*, in press.

Salo, K. 1998: Kotka Ecopower IGCC-Project, the attempt to transfer the biocycle project to Finland. *Biomass and Bioenergy* Vol.15, No.3, pp.225-228.

Scoditti, E. 2002: Gasification survey country: Italy. In Kwant, K.W and Knoef, H. (Ed): Status of gasification in countries participating in the IEA & GasNet activity, September 2002. www.gastechnology.org/iea 20 July 2004.

Ståhl, K.; Neergaard, M. 1998: IGCC power plant for biomass utilisation, Värnamo, Sweden. *Biomass and Bioenergy* Vol. 15, No. 3: 205-211.

Ståhl, K.; Neergaard, M.; Nieminen, J.; Stratton, P. 1997: IGCC power plant for biomass utilisation , Värnamo, Sweden. In A.V.Bridgwater and D.G.B. Boocock (Ed) *Developments in Thermachemical Biomass Conversion*, Vol 2 p1006-1015. Blackie Academic & Professional.

Williams, R.H.; Larson, E.D. 1996: Biomass gasifier gas turbine power generating technology. *Biomass and Bioenergy*, Vol. 10, Nos 2-3, p149-166.