

Biomass-fuelled cogeneration: Potential applications in China

Guoquan Qiu^{1*}, Hao Liu², Saffa Riffat³

**^{1,2,3}School of the Built Environment, the University of Nottingham,
University Park, Nottingham, NG7 2RD, UK**

*¹Email: laxgq@nottingham.ac.uk

²Email: liu.hao@nottingham.ac.uk

³Email: saffa.riffat@nottingham.ac.uk

ABSTRACT: China's continual increase in energy demand and its heavy reliance on coal combustion are a compelling motivation for the adjustment of Chinese energy structure. China is the biggest agricultural country and 80% of its population live in rural areas. Biomass, an organic matter, such as wood, crops and animal wastes, is a significant source of energy in China today, particularly in the countryside. However, the current use of biomass such as firewood and agricultural residues is largely for cooking and heating using traditional stoves which are of low energy efficiency and produce various air pollutants. This article firstly addresses the potential size of the biomass resource in China. Some novel advanced biomass technologies which may play a significant role in China's energy system in the long term and appropriate to be developed in China, are reviewed. As some populations in China still live in remote rural areas and islands without electricity, biomass-fuelled cogeneration suitable for applications in these areas is finally discussed.

Key words: China, biomass, cogeneration, gasification, organic Rankine cycle

1. INTRODUCTION

Biomass energy or bioenergy, i.e., the energy derived from biomass is one of the main source of energy in many developing countries, such as China. Currently bioenergy provides about 55EJ (equivalent to 25 million of barrels oil/day), or about 14% of the world's energy, and potentially as much as 450EJ by mid 21st century, an 8-fold increase [1]. In developing countries, as a whole, bioenergy represents about 34% of the total energy, both in its traditional and modern forms, and varies from about 90% in countries like Nepal, Rwanda, Tanzania and Uganda, to 45% in India and 28% in

China [1]. Much of bioenergy originates from varieties of agricultural and forest residues. The diverse use of biomass utilization is well represented in the so-called six Fs: "food, fuel, feed, feedstock, fibre, and fertiliser". Biomass was the main source of the world energy up to the early 20th century. Biomass energy has played and continues to play a major role in rural developments of many countries. Today's main challenge in biomass energy is to provide what people need, e.g. clean, cheap and convenient energy such as electricity, and ethanol fuel, in an environmentally sound manner. Currently the main use of

bioenergy in many developing countries is still in its traditional forms, such as cooking stoves. And this is where the main problem lies because of the low energy efficiency. Associated with traditional biomass utilization methods, the energy efficiency varies considerably e.g. from about 2% to 20% of a biomass utilization method for cooling stoves in developing countries, to 80% or higher for biomass heating boilers in industrial countries. Low efficiency results in not only enormous waste of resources but also potentially serious environmental problems. Therefore bioenergy production and use in many developing countries must be modernised. Bioenergy utilisation and rural development are intrinsically intertwined. Efficient production and utilisation of bioenergy in both developing and developed countries can make a significant contribution to social and economic development in rural areas.

2. BIOMASS ENERGY IN CHINA

China has world's largest population (1.3 billion) and around 60% of the population live in rural regions. There are over 800 million people and over 245.1 million households in rural areas, although rural population ratio is gradually decreasing from 82% in 1978 to 60% at present[2]. Chinese agricultural sector employs over half of the national labour force mainly engaging in traditional agricultural production methods to produce food for the whole nation. Biomass from agricultural production, such as crop residues, is a significant source of energy in China today, particularly in rural areas. The principal biomass resources in China include [3]: (1) residues from agriculture and forest industries, (2) animal manure from medium and large-scale livestock farms, and (3) municipal solid waste (MSW). As China is the largest agricultural country in the world, its biomass resources are very plentiful and have huge potential. There is around 600Mt crop residues every year in China and at least half of them may be used to supply

biomass energy after some of them are used as fodders, fertilizers and industrial materials etc. However, the current use of firewood and agricultural residues by direct combustion for cooking and heating in rural areas results in detrimental effects of indoor air pollution and associated adverse health impacts. Currently, 61% of the rural household energy in china comes from traditional use of biomass. This means that each year approximately 4 billion tons of crop residues and wood fuel are burnt by using inefficient stoves. On the other hand, a new rising severe air pollution problem in rural China comes from the open-field burning of crop residues at harvest time, as shown in Figs. 1 & 2 [4]. 12% of straw residues are burned this way as some rich farmers have become less willing to gather residues from the fields and store them for their energy use throughout the year and instead they prefer to buy coal briquettes or liquefied petroleum gas (LPG). The use of clean, low-cost biomass fuels for heat and power in rural areas based on modern efficient biomass technologies could significantly increase living standards and promote rural industrialization and employment in rural areas.



Figure 1: Problems of in site burning of straw in the field

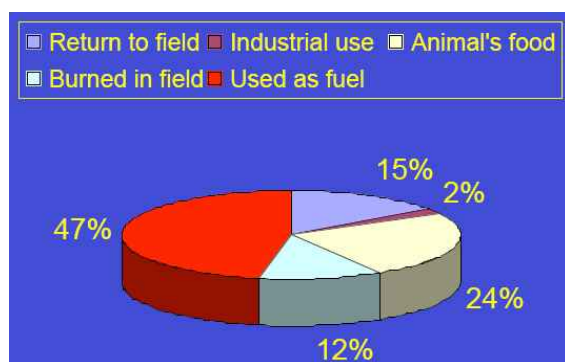


Figure 2: Share of straw usage in China [4]

Furthermore, China is facing great challenges to meet its ever increasing energy demand and to reduce environmental pollution. Currently, China uses around 6% of world petroleum production as the second largest petroleum consumer (USA uses about 28% of the world petroleum supply). China became a net importer of petroleum from other countries in 1993 and petroleum imports increased to about 865 million barrels in 2005, accounting for about 42.9% of total petroleum consumption in China [5]. China, as the world's leading developing

economy, has the opportunity to become a global leader in developing and applying renewable energy technologies, including biomass cogeneration.

The Chinese government, foreseeing tough energy challenges, has introduced various energy legislations. A renewable energy law came into force on 01 January 2006 to accelerate the development and deployment of renewable energy, including wind, solar, hydro, and biomass. An energy saving law was also executed on 01 April 2008. Fig. 3 shows the rural energy-supply framework in China. Fossil fuels from outside, i.e., non-planned supplies for rural areas, have become deficient and expensive. Electricity from state-owned grids in China rural regions is only used to power lamps and electric appliances. The energy for hot water, space heating and cooling is mainly from local energy resources, such as biomass energy which is reliably available and plentiful.

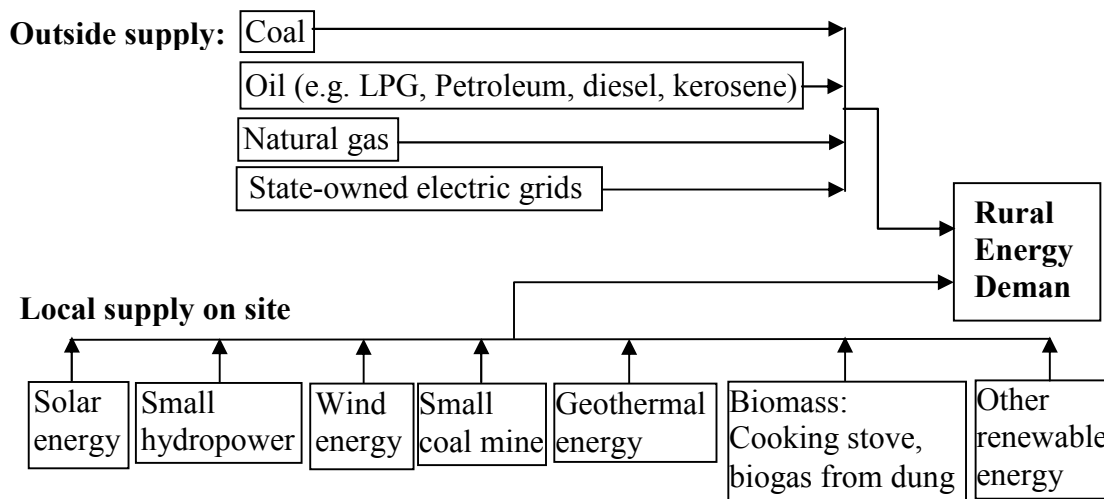


Figure 3: Rural energy-supply framework in China [2]

Some modernized biomass energy technologies are currently being developed and demonstrated in China, including biogas; gasification of straw, stalk and rice husk [6]; biomass-fired power generation and liquid biofuels. Biogas is largely produced by anaerobic digestion of livestock manure and the total number of

rural household biogas digesters reached around 17 millions by the end of 2005 in China [7].

A gasification system can be more economically attractive when it combines the production of gas for cooking and heating with that of electricity. Li et al. [3] compared the benefits of three types of stalk

gasification systems: cooking gas only; cooking and electricity; cooking, heating and electricity. It was concluded that more benefits could be achieved with a gasification-based cogeneration system. 525 village-scale gasification stations fuelled with straw and stalk etc. were reported in operation throughout China in 2004.

3. BIOMASS-FUELLED POWER GENERATION TECHNOLOGIES

3.1 STATE OF THE ART

Biomass-fuelled power generation may be implemented by means of a thermal process, e.g. direct combustion or gasification or pyrolysis[8], as shown in Fig. 4, followed by a power generation cycle(e.g.

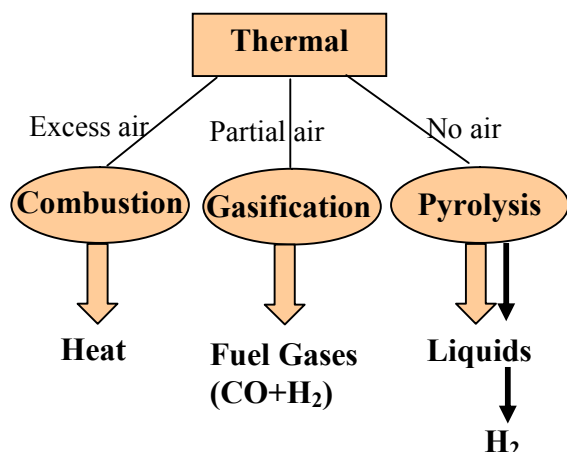


Figure 4: Three types of thermal processes for biomass-fuelled power generation

steam turbine cycle). Direct combustion involves the complete oxidation of biomass with excess air, providing boilers with heat to produce steam which can be used to generate electricity in a Rankine cycle. In air-based gasification cycles, biomass is partially oxidized by sub-stoichiometric amounts of oxygen to provide energy for thermal conversion of the remaining biomass to a mixture of carbon monoxide and hydrogen. In pyrolysis processes, indirect heating in the absence of oxygen is used to convert biomass to a mixture of gases and organic condensible liquids. The combustible gases and liquids resulted from

gasification or pyrolysis processes may be used in several thermodynamic cycles to generate electricity, as shown in Fig. 5. For instance, a 2.5 MW_e biomass gasification power generation module was developed by Wellman Process Engineering Limited [9]; a 250 kW_e downdraft gasifier for CHP was demonstrated by Biomass Engineering Ltd [10]; a small-scale biomass gasification CHP system (proposed 50 kW_e and 10 kW_e electrical loading application) was investigated by Gallagher [11].

Although different thermodynamic cycles and thermal processes shown in Fig. 5 have their own merits and demerits, the organic Rankine cycle (ORC) should be highlighted because of its potential for small-scale biomass CHP. ORC is generally applied at lower pressures and temperatures. Operations at lower pressures and temperatures could increase safety, and also reduce the complexity and cost of ORC systems. Good safety and low costs are required for small-scale domestic biomass-fuelled CHP units. In the medium-scale power range (300-1500 kW_e), as shown in Fig. 5, the ORC process has proven its technological maturity and is ready for the commercial market. However, micro-scale biomass-fuelled ORC-based CHP units (<10kW_e) suitable for domestic applications have not been demonstrated or commercialized. The authors are currently developing a 2kW_e micro-scale biomass-fired ORC-based CHP system in the University of Nottingham.

3.2 CURRENT STATUS IN CHINA

Several biomass-fuelled power plants have recently been demonstrated and commercialized in China:

(1) Shanxian 25MW_e biomass-fired power plant

China's first biomass-fired power plant, with an installed generating capacity of 25 MW_e, went into commercial operation in 2006 in Shanxian County, Shandong Province [12]. The plant burns 150,000 to

200,000 tons of cotton stalks, tree branches, orchard and forestry waste annually. It can generate 160 million kWh of electricity per year, saving the equivalent of 400,000 tons of coal. Local farmers and biomass

enterprises can earn about 5.8 million US\$ from the project per year. The ash of the burned biomass is largely returned to the farmland as the ash is a good quality potash fertilizer.

Biomass-based CHP Technologies --- Electrical power range & efficiencies in 2003

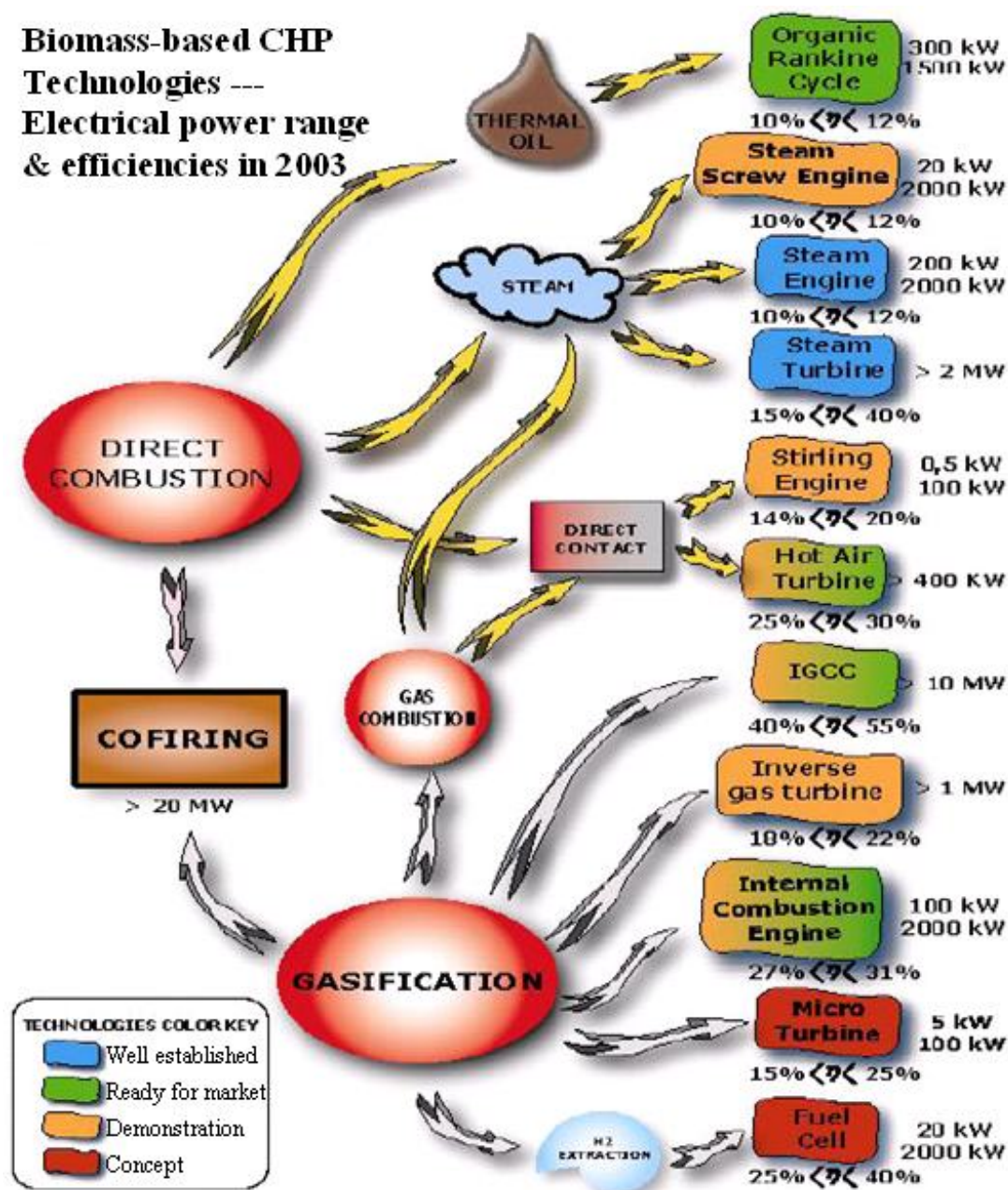


Figure 5: Biomass-fuelled CHP technologies [13]
---Electrical power range and efficiencies in 2003 by Jeremy Hugues
(IGCC-- Integrated Gasification Combined Cycle)

(2) Wangkui 30MW_e biomass-fired power Plant

A biomass-fired power plant that burns plant and vegetable stalks to generate electricity went into operation in 2007 in the

Northeast China's WangKui county, Heilongjiang Province. The power plant, with an installed capacity of 30MW_e, is expected to burn more than 200,000 tons of

stalks annually and generate 175 million kWh of electricity.

(3) Huaneng Changchun 50MW_e biomass-fired power plant

Huaneng Changchun Biomass Power Plant, expected to be operational by August 2009, has an installed capacity of 50 MW_e and generates as much as 180 million kWh of electricity annually after its completion. It will consume 200,000 tons of crop straw annually, equivalent to savings of 85,000 tons of coal per year. Meanwhile, the heat produced by burning straw will provide heat for space heating of 1.8 million m² building areas. The CHP efficiency of the plant could be as high as 90 percent. Crop straw previously was burned on farmlands, causing resource waste and air pollution. Farmers will make 7.2 million US\$ annually by selling crop straw to the power plant. Ashes of the burned crop straws will be returned to the farmers for use as fertilizer.

More and more biomass-fired cogeneration plants have been completed or under construction in China. Many of them are gasification plants using crop residues to provide fuel gases for cooking and electricity generation. Hundreds of such village-scale straw gasification plants throughout China are being demonstrated. Gasification device units are also commercially available in China [6].

4. APPLICATION POTENTIAL FOR NOVEL COGENERATION IN CHINA

Biomass energy, particularly novel cogeneration systems, must have huge potential market in China because:

- (1) China is the world's largest agricultural country rich in biomass resource, such as agricultural residues, forest residues and livestock dung etc.
- (2) Biomass-fuelled electricity generation can be stable and reliable in contrast to other intermittent renewable energy sources, such as hydropower, wind power and solar power et al.

(3) Demand for electricity in China has risen by 60% since 2000, and there is an urgent need to reduce the proportion of coal-fired electricity generation in China. China uses one third of global coal supply to generate 80% of its electricity and 75% of the energy for home heating. Excess coal use has resulted in serious air pollution, particularly NO_x and SO_x – the precursors of acid rains. As biomass combustion is nearly carbon neutral and produces much less pollutants, such as NO_x and SO_x than coal combustion, biomass-fuelled electricity generation is a good option to replace coal-fired electricity generation in China.

(4) China has started the campaign of building a new progressive countryside (<http://www.xinnongcun.gov.cn>). Outdated rural energy structures must be modernized in order to comply with the new rural structures. Biomass-fuelled electricity generation may be the best method to solve the electric supply problem for 4-5 million households, i.e., around 15 millions Chinese people in remote areas and islands who have not had access to electricity in 2006 [7].

(5) Biomass-fuelled cogeneration technologies have advanced over the past years. Further developments in micro-scale (<10kW_e) biomass-fuelled cogeneration will be particularly relevant to its applications in rural areas of China.

(6) The Chinese government are promoting the applications of renewable energy technologies by means of relevant legislations and governmental policies.

The Centre for Renewable Energy Development (CRED) in Beijing provided the projections for the new increments of biomass power capacities in China during 1998-2020, as shown in Table I [3]. The projected installed biomass power capacities are expected to increase significantly over the next decade in China but they will be still well below the potential capacities in 2020.

Table I: CRED projections of added biomass power capacity, 1998-2010 [3]

Resource	1998 installed capacity (MW _e)	Projected added capacity during indicated period (MW _e)			Capacity in 2020 (MW _e)	
		1998-2005	2005-2010	2010-2020	Projected installed	Potential capacity
Landfill gas	0	30	30	540	600	4,650
MSW	15	85	150	710	960	23,330
Biogas	2	25	125	150	302	630
Bagasse	410	20	40	130	600	2,380
Straw	3	25	125	150	303	43,850

5. CONCLUSIONS

Biomass energy resource is extremely plentiful in the world due to its diversity. Biomass energy supply can be stable and reliable in contrast to other intermittent renewable energy resources.

Biomass is renewable as its combustion produces no net CO₂ emissions to the environment.

China is a developing agricultural country with huge biomass energy resource. Biomass energy is an easily available and affordable energy source in China.

Biomass-fuelled cogeneration technologies have advanced significantly over the past

years and their further developments in micro-scale (<10kW_e) biomass-fuelled cogeneration are particularly relevant to its applications in rural areas of China.

ACKNOWLEDGEMENT:

The authors wish to acknowledge the financial support from UK EPSRC (EP/E020062/1) via ERA-NET Bioenergy for the current research project on Small-Scale Biomass-Fired CHP System at School of the Built Environment of the University of Nottingham.

REFERENCES:

- [1] Frank, RC. 2003. The role of biomass energy in rural development. In Proceedings of the 3. Encontro de Energia no Meio Rural, Campinas (SP, Brazil). Brazil.
- [2] Catania, P. 1999. China's rural energy system and management. Applied Energy. Vol 64. No1-4. pp229-240. Canada.
- [3] Li, JJ, Zhuang, X, Pat, D & Eric, DL. 2001. Biomass energy in China and its potential. Energy for Sustainable Development. Vol 5. No4. pp66-80. China.
- [4] Lin, W, Barz, M & Li, J. 2003. Prospects of Successful Energetic Utilization of Biomass in China, in Sino-German Workshop on Energetic Utilization of Biomass, Beijing, China October 8-11. Beijing. China.
- [5] Yang, B & Lu, YP. 2007. The promise of cellulosic ethanol production in China. Journal of Chemical Technology and Biotechnology. Vol 82. No 1. pp6-10. USA.
- [6] Peako biomass energy. 2008. <http://en.peako.net/> Retrieved on 17 June 2008. China.
- [7] Martinot, E. 2008. Renewable energy information on markets, policy, investment and future pathways. <http://www.martinot.info/china.htm>. Retrieved on 11 July 2008. China.
- [8] Bain, RL, Overend, RP & Craig, KR. 1998. Biomass-fired power generation. Fuel Processing Technology. Vol 54. No 1-3. pp1-16. USA.
- [9] McLellan, R. 2000. Design of a 2.5 MW(e) biomass gasification power generation module, Report ETSU B/T1/00569/REP. Wellman Process Engineering Limited. pp1-43. UK.
- [10] BiomassEngLtd. 2006. Development of a 250kWe downdraft gasifier for

CHP, Biomass Engineering Ltd, Report
DTI Project No PS251. pp1-9. UK.

- [11] Gallagher, GJ. 2002. Development of a small-scale biomass CHP system, Report funded by DTI, contractor: Sustainable Energy Ltd. pp1-41. UK.
- [12] Shanxian county biomass-fired power plant. 2008.
<http://www.danishcdm.um.dk/en/menu/Projects/China/ShanxianBiomassPowerPlant/>
Retrieved on 17June 2008. Denmark.
- [13] Scahill, J. 2003. Biomass to Energy: Present Commercial Strategies and Future Options, NREL,, in Healthy Landscapes, Thriving Communities: Bioenergy and Wood Products Conference. pp1-28. USA.