An Advanced Biomass Gasification Technology

Project Results

Lead organisation: Renergi Pty Ltd

Project commencement date: 9 November 2012  Completion date: 15 January 2018

Date published:

Contact name: Chun-Zhu Li

Title: John Curtin Distinguished Professor

Email: chun-zhu.li@renergi.net  Phone: 08 9266 1131

Website: www.renergi.net
Table of Contents

Table of Contents ........................................................................................................................................2
Executive Summary ....................................................................................................................................3
Project Overview .......................................................................................................................................4
  Project summary .....................................................................................................................................4
  Project scope ........................................................................................................................................4
Outcomes ................................................................................................................................................5
Transferability ..........................................................................................................................................9
Publications .............................................................................................................................................10
Intellectual Property: Patents / Licences ...............................................................................................11
Awards ...................................................................................................................................................11
Conclusion and next steps ..................................................................................................................11
Appendix ...............................................................................................................................................13
Keywords .................................................................................................................................................13
Executive Summary

The ultimate aim of this project is to demonstrate the advanced biomass gasification technology originally developed by the researchers led by Professor Chun-Zhu Li in Curtin University to the biomass processing capacity of 100 kg/hr. The project has now been successfully completed and met all objectives of the project.

During the course of this project, a 100 kg/hr biomass gasification demonstration plant was designed, constructed, commissioned and operated to prove the technical feasibility of this advanced gasification technology. A large number of trials have been carried out using mallee biomass and wheat straw grown in WA agricultural regions as the feedstocks. The product gas quality has been monitored both with an on-line gas analyser and by sampling for subsequent off-line analysis.

The trials were carried out under a wide range of conditions. The demonstration plant performed very well, meeting or exceeding the design specifications. The results from the trials have demonstrated that this technology is capable of producing gasification product gas with low contents of tar and particulates and high heating values, which will be suitable for direct use in a gas engine to generate electricity and/or heat. A mass and energy balance process model has been developed.

This project has generated a large amount of intellectual property, including 2 patent applications and technical know-how. This project has increased the technology readiness level (TRL) of the technology from TRL 5 to 7. This technology has many unique features, including

- Feedstock flexibility and minimal preparation. Most of commonly available biomass resources can be used as its feedstock. The feedstock can contain a wide range of particle sizes, ranging from microns to centimetres. Bio-oil can also be a feedstock.
- Fast gasification rates under mild reaction conditions.
- High efficiency. This is due to the minimisation of oxygen consumption and the incorporation of energy recovery and recuperation in the technology design.
- Hot gas cleaning using biochar as a catalyst and adsorbent. It converts or removes a wide range of organic and inorganic impurities in the raw gasification product gas. Other suitable carbon materials may also be used as a catalyst. It eliminates the need of a liquid scrubbing process that is commonly used in conventional hot gas cleaning processes.
- Versatility for commercial operation. The technology can be deployed for power generation at small or relatively large scales. It can be used for co-firing biomass with coal or natural gas.
- Negative emission can be achieved while generating base-load/dispatchable green electricity without the need of an energy storage device.

Therefore, this technology represents a significant advance in the development of gasification technologies in the world.

The economic assessment has shown the economic competitiveness of this technology in the generation of base-load/dispatchable green electricity.

A commercialisation strategy has been formulated. Renergi is planning to build the first commercial scale biomass gasification plants using this technology. The commercialisation of this technology will help to secure Australia’s global leading position in the field of bioenergy.
Project Overview

Project summary

This project aims to demonstrate the advanced biomass gasification technology originally developed by the researchers led by Professor Chun-Zhu Li in Curtin University to the biomass processing capacity of 100 kg/hr.

During the course of this project, a 100 kg/hr biomass gasification demonstration plant was designed, constructed, commissioned and operated to prove the technical feasibility of this advanced gasification technology. A large number of trials have been carried out using mallee biomass and wheat straw grown in WA agricultural regions as the feedstocks under a wide range of conditions. The product gas quality has been monitored both with an on-line gas analyser and by sampling for subsequent off-line analysis.

The demonstration plant performed very well, meeting or exceeding the design specifications. The results from the trials have demonstrated that this technology is capable of producing gasification product gas with low contents of tar and particulates and high heating values, which will be suitable for direct use in a gas engine to generate base-load electricity and/or heat. A mass and energy balance process model has been developed.

The project has now been successfully completed, meeting all objectives of the project. This project has demonstrated the technical feasibility of this advanced biomass gasification technology. This project has increased the technology readiness level (TRL) of the technology from TRL 5 to 7. The economic assessment has shown the economic competitiveness of this technology in the generation of green base-load/dispatchable electricity. This technology represents a significant advance in the development of gasification technologies in the world.

A commercialisation strategy has been formulated. Renergi is planning to build the first commercial scale biomass gasification plants using this technology. The commercialisation of this technology will make important contribution to the emerging bioenergy industry in Australia.

Project scope

Gasification will be a vitally important energy technology in the carbon-constrained future. Via gasification, a solid fuel or a mixture of solid fuels can be used to generate base-load/dispatchable
electricity, to produce hydrogen, liquid fuels and chemicals. Biomass is a particularly attractive feedstock for gasification due to its high reactivity during gasification.

Biomass has distinctly different properties from coal. The development of an advanced biomass gasification technology must consider the special features of biomass as a fuel for gasification:

- **Very high volatile yields.** Upon heating, a very substantial fraction of biomass would be transformed into gaseous components, termed as volatiles. A direct consequence is that the raw gasification product gas can have high contents of tar residue, negatively impacting its subsequent use. The existing water-scrubbing process to remove tar can generate a stream of wastewater, requiring expensive treatment before its disposal. A major technological breakthrough is required to convert tar into useful products without generating a stream of wastewater.

- **Strong volatile-char interactions.** The extensive research, particularly that led by Professor Chun-Zhu Li in Curtin University, has shown that volatile-char interactions can influence almost every aspect of gasification, including the termination of char gasification. An advanced biomass gasification technology should minimise the negative impacts of the volatile-char interactions.

- **High contents of potassium and other inorganic species.** These species can volatilise easily, contaminating the raw gasification product gas. They must be removed, ideally together with tarry material in the product gas. These inorganic species can also cause ash-related problems such as slagging during gasification, which must be carefully managed.

Based on intensive fundamental research, the team led by Professor Chun-Zhu Li developed an innovative biomass gasification technology. The technology overcomes the above-mentioned problems associated with the special properties of biomass, showing great promise to be a commercially competitive and highly efficient biomass gasification technology. The technology was demonstrated with a lab-scale pilot plant at around 4 kg/hr biomass processing capacity and protected by a patent application (PCT/AU2011/000936).

The purpose of this project has been to scale up this award-winning proprietary technology from 4 kg/hr to 100 kg/hr in order to obtain key technical information for the design and operation of commercial biomass gasification plants using this technology. This project has been a critical step in the overall research-development-deployment value chain to commercialise this novel technology.

**Outcomes**

**Design, Construction, Commissioning and Operation of a 100 kg/hr Demonstration Plant**

A 100 kg/hr biomass gasification demonstration plant has been successfully designed, constructed, commissioned and operated during this project. Figure 1 shows a photo of the demonstration plant,
located in the Technology Park, Perth, Western Australia. The whole demonstration plant includes the following key sub-systems: a biomass drier, a biomass transferring and feeding sub-system, a pyrolyser, a gasifier, a hot gas cleaning and energy recuperation unit and a flare to burn all product gases before their release to the atmosphere.

Figure 2 shows the working principle of this technology. For biomass that has a high moisture content, it will be firstly dried to remove some of its moisture. There is no need to remove all the moisture. The
biomass will then be pyrolysed to produce a gaseous intermediate product called volatiles and a solid intermediate product called biochar. The biochar will be gasified with air and steam in the practical absence of volatiles in the same gasifier where volatiles will also be reformed. In other words, the gasification of biochar and the reforming of volatiles will take place in different zones in the same reactor. The raw gasification product gas from the gasification of biochar and the reforming of volatiles will be cleaned in a hot gas cleaning and energy recuperation unit. The organic and inorganic impurities such as tar residue and vaporised metallic species (e.g. potassium) in the raw gasification product gas will be either chemically converted or physically removed as the hot product gas is cooled down. Energy recuperation will also take place to convert the thermal energy into chemical energy. In future commercial operation, the clean product gas will be used in a gas engine or other types of power generation equipment (e.g. fuel cells) to generate electricity and/or heat. However, as the gas engines are considered as a commercial technology and do not form part of this project, the clean product gas is burned in a flare in the demonstration plant before its release to the atmosphere.

As is shown in Figure 2, in the future commercial operation, the heat embedded in the hot gasification product gas and the heat in the flue gas from the engine(s) will be recovered and used to meet the energy demand for biomass pyrolysis and drying.

A large number of trials have been carried out using mallee biomass and wheat straw as its feedstocks. Both were grown in WA. Figure 3 shows some typical photos of the biomass used in these trials. It should be noted that the feedstocks contain a wide range of particles ranging from microns to centimetres.

A large number of trials were carried out in this project under a wide range of conditions. These trials have shown that the demonstration plant has performed very well, meeting or exceeding the design specifications. Importantly, these trials have demonstrated that the technology could produce gasification product gas with low contents of tar and particulates and high heating values, meeting the quality requirement for the gas to be used directly in a gas engine to generate electricity and/or heat.

Features of This Biomass Gasification Technology

These trials have demonstrated some key features of this technology:

- **Feedstock flexibility and minimal preparation.** The mallee (woody) biomass and wheat straw used in this project have covered the properties of a wide range of biomass resources, especially forestry wastes, woody plantations and agricultural wastes.

  A wide range of particle sizes, ranging from microns to centimetres, can be in the same feedstock, reducing the cost of biomass preparation. In particular, the extensive grinding of biomass to very fine particles is not necessary.

  Organic liquids, such as bio-oil, can also be a potential feedstock for this technology.
• **Fast gasification rates under mild reaction conditions.** This technology can achieve rapid gasification under relatively mild conditions of atmospheric pressure and relatively low temperatures (<1000°C or even lower).

• **High efficiency.** Based on the data obtained in this project and those from the previous pilot plant, our simulation predicts that cold gas efficiencies of over 90% (HHV) for future commercial operation would be possible.

• **Hot gas cleaning.** Without using a liquid scrubbing process, our technology can produce clean gasification product gas that meets the quality requirement for its direct use in gas engines.

• **Versatility for commercial operation mode.** This technology can be used for small scale distributed power generation or relatively large scale power generation.

---

**Figure 3.** The biomass feedstocks used in trials.
The technology may also be used for co-firing biomass with coal or natural gas. Some components of this overall technology can also be used with other technologies, including the retrofitting of existing gasification plants.

- **Negative carbon emission.** This technology allows for the biochar to be withdrawn from the overall process and to be returned to the soil for carbon sequestration with added benefits of improved soil fertility. As the carbon in biochar has originated from the CO₂ in the atmosphere, the net effect is the negative carbon emission while base-load/dispatchable electricity is generated.

### Technology Readiness Level of This Technology

Prior to the commencement of this project, the technology readiness level was assessed as Level 5 with some aspects reaching Level 6. At the conclusion of this project, the technology readiness level is assessed as Level 7 with some aspects reaching Level 8.

### Economic Competitiveness of This Technology

The economic competitiveness of this technology is clear. In particular, power generation using this technology requires much lower capital investment on a per kWh basis than many other renewables such as wind and solar. This reduces the need to secure large amounts of capital as the technology is widely deployed in the future.

Reducing the cost of biomass transportation is an important way to reduce the cost of electricity. Power generation using the bio-oil produced with distributed pyrolysers appears to be particularly attractive.

Enormous direct and indirect social, economic and environmental benefits will accrue from the commercialisation of this technology. For example, a large number of high quality jobs can be created for the growth, harvesting and processing of biomass in regional Australia.

This technology is particularly competitive when renewable base-load/dispatchable electricity is to be generated as it does not require energy storage facilities to generate base-load or dispatchable electricity. Indeed, biomass itself is the cheapest form of energy storage.

### Transferability

Bioenergy will continue to play a critical role in our future energy supply. Biomass is one of very few renewable energy sources that can be used directly to generate base-load/dispatchable electricity without the need of an energy storage device. Bioenergy will be of particular importance to stabilise our grids as we continue to increase the proportion of renewables in our energy supply.

The cost to centralise distributed biomass to achieve relatively large scale power generation is a significant part of the overall cost of electricity. This technology can be deployed together with a
pyrolysis technology (e.g. Renergi’s grinding pyrolysis technology) to drastically reduce this cost. To this end, biomass can be firstly pyrolysed using transportable pyrolysers to produce bio-oil and biochar at locations where biomass is grown. While biochar is used for many other purposes, bio-oil can be transported and centralised for reforming to produce clean gasification product gas using this technology. The transportation of liquid bio-oil would be much cheaper than the transportation of bulky biomass, greatly improving the economic competitiveness of power generation using distributed biomass. It should be noted that the gasification-based power plant using bio-oil as the feedstock would be a lot simpler than that using biomass as the feedstock.

In addition to being part of this overall biomass gasification technology, the novel pyrolysis technology developed in this project can also be operated as standalone pyrolysers, including being designed to be compact and transportable to where biomass is grown.

Possibility exists to produce carbon materials and generate electricity simultaneously to further improve the economic competitiveness of this technology. This deserves further investigation.

The gasification of solid fuels and the reforming of liquid/gaseous fuels are currently the main commercial processes to produce hydrogen. This technology can be deployed to produce exportable renewable hydrogen.

Biomass is the only renewable that can be used directly to produce liquid fuels and chemicals that are currently produced using fossil fuels. The hydrotreatment of bio-crudes (e.g. bio-oil) from the pyrolysis or hydrothermal liquefaction of biomass is one such promising route to convert biomass into liquid fuels and chemicals. However, hydrogen is an indispensable feedstock and the cost of hydrogen production largely influences the overall economic feasibility of the biofuel process. Importantly, this technology can also be used to produce hydrogen using biochar and/or hydrotreatment wastes for the hydrogen to be used as a feedstock to the hydrotreatment unit within the same plant. Indeed, this advanced biomass gasification technology will be very important for the future commercialisation of Renergi’s biofuel technology that is currently being developed.

Alternatively, this technology can also be used to produce syngas for the subsequent synthesis of liquid fuels and chemicals.

**Publications**


Intellectual Property: Patents / Licences

This project has started from the technology disclosed in the following patent application. During the course of this project, patent rights have been granted in a number of countries:

- C.-Z. Li, H. Wu, M. Asadullah and S. Wang. A method of gasifying carbonaceous material and a gasification system, PCT/AU2011/000936; Owner: Curtin University of Technology but licensed to Renergi Pty Ltd. Patent rights have been granted in Australia (2011284780, 1 Oct 2015), New Zealand (607367, 30 June 2015), Singapore (187594, 31 July 2015) and China (ZL 2011 8 0045572.6, 30 June 2017). The examination continues in other jurisdictions.

This project has created a large amount of intellectual property, especially the following patent applications:

- C.-Z. Li, L. Dong and R. Gunawan, Process and apparatus for cleaning raw product gas, PCT/AU2014/001135; Owner: Renergi Pty Ltd. The examination has commenced in various jurisdictions. Notice of allowance in USA was received on 29 August 2017.
- C.-Z. Li, R. Gunawan and L. Dong, Apparatus for pyrolysing carbonaceous material, PCT/AU2014/001137; Owner: Renergi Pty Ltd. The examination has commenced in various jurisdictions.

Awards

Renergi Pty Ltd was shortlisted for the Best Business Start-up Award, Institution of Chemical Engineers (IChemE) Global Awards, UK, 2015.

Conclusion and next steps

This project has successfully scaled up an advanced biomass gasification technology to a nominal biomass processing capacity of 100 kg/hr. A dedicated demonstration plant has been designed, constructed, commissioned and operated very successfully. A large number of trials have been completed using mallee (woody) biomass and wheat straw as its feedstocks to demonstrate the technical feasibility of the technology for the gasification of a wide range of non-food lignocellulosic biomass resources. This project has created a large amount of commercially valuable intellectual property, including patents and technical know-how.
This project has achieved all of its objectives. The technology is ready for further commercialisation. Renergi Pty Ltd is now planning to build commercial plants using this technology. The successful commercialisation of this advanced biomass gasification technology will make a significant contribution to the emerging bioenergy industry in Australia and help to secure Australia’s global leading position in this important field of bioenergy.
Appendix

Keywords
Biomass; gasification; pyrolysis; hot gas cleaning; demonstration; tar removal; mallee; straw, base-load; dispatchable; bio-oil; biochar; negative emission.