A Low Emission Biofuel Technology

Project results and lessons learnt

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Executive Summary

This project aims to develop and demonstrate a suite of low-emission biofuel technologies developed by Renergi/Curtin researchers, consisting of three inter-related technology components:

- the grinding pyrolysis of biomass to produce biochar and bio-oil,
- the hydrotreatment (biorefinery) of bio-oil to produce liquid fuels and chemicals, and
- the production of solid biocarbon materials from bio-oil and/or biochar.

During the course of this project, a 100 kg/hr biomass grinding pyrolysis demonstration plant has been designed, constructed, commissioned and operated to prove the technical feasibility of this advanced pyrolysis technology. A large number of trials have been carried out using mallee woody biomass and agricultural residues as feedstocks. The technology is capable of pyrolysing a very wide range of biomass resources and wastes to produce high quality biochar and bio-oil. In particular, a wide range of biomass particle sizes, ranging from microns to centimetres, can be present in the same feedstock, greatly saving the capital and operating costs for biomass feedstock preparation. The technology can also be operated in the mode of oxidative pyrolysis, greatly facilitating the heat supply to the pyrolysis system in commercial operation.

During the project, a 20 L/hr bio-oil hydrotreatment demonstration plant has been designed, constructed, commissioned and operated with the bio-oil produced in the 100 kg/hr grinding pyrolysis demonstration plant. A large number of trials have been carried out under a wide range of conditions. The biofuel products can meet the majority of Australian fuel quality standards for petrol, diesel or related fuels. The outcomes of this project will help to formulate future Australian standards for biofuels from non-food lignocellulosic biomass resources.

Significant progress has also been made in the development and demonstration of Renergi's biocarbon technology for the production of biocarbon materials using biochar and bio-oil from the grinding pyrolysis of biomass. The biocarbon materials, including biocarbon composites, will find a wide range of commercial uses as solid fuels, reductants and specialty materials in energy industry, metallurgical industry and chemical industry.

The above-mentioned technologies are protected with 5 patents, patent applications and/or technical know-how. Knowledge sharing has been an important part of project activities, including presentations in conferences, publications in journals and direct dissemination of project outcomes to governments, industry, investors and researchers.

The commercialisation of the outcomes from this project will help to secure Australia's global leading position in the field of bioenergy.

Project Overview

Project summary

This project aims to develop and demonstrate a suite of low-emission biofuel technologies consisting of three inter-related components:

- *Renergi's biomass grinding pyrolysis technology* to convert non-food lignocellulosic biomasses and wastes into bio-oil and biochar.
- *Renergi's bio-oil hydrotreatment technology* to upgrade bio-oil into high quality liquid fuels and chemicals.
- *Renergi's biocarbon technology* to produce solid biocarbon materials and biocarbon composites from bio-oil and/or biochar.

During the course of this project, a 100 kg/hr biomass grinding pyrolysis demonstration plant has been designed, constructed, commissioned and operated. A large number of trials have been carried out using mallee woody biomass and agricultural residues as feedstocks. These trials have aimed to demonstrate the technical feasibility of Renergi's grinding pyrolysis technology in processing a wide range of non-food lignocellulosic biomass resources.

During the course of this project, a 20 L/hr bio-oil hydrotreatment demonstration plant has been designed, constructed, commissioned and operated with the bio-oil produced in the 100 kg/hr grinding pyrolysis demonstration plant. A large number of trials have been carried out under a wide range of conditions. These trials have aimed to further develop and demonstrate the technology for the production of liquid biofuels and chemicals.

During the course of this project, significant progress has also been made in the development and demonstration of Renergi's biocarbon technology for the production of biocarbon materials using biochar and bio-oil from the grinding pyrolysis of biomass. The biocarbon materials, including biocarbon composites, will replace many solid carbon materials that are currently derived from coal and petroleum.

This project has created a large amount of intellectual property in the form of patents, patent applications and know-how, which will play a critical role in the establishment of an Australian bioenergy industry. Knowledge sharing activities have been an essential part of this project to disseminate the project outcome to a wide range of stakeholders of Australian bioenergy industry, including government, industry, inventors and researchers.

This project has now been successfully completed and met all objectives of the project.

Project scope

Australia has abundant high quality biomass resources, including forestry and agricultural/horticultural wastes. With its vast land, even excluding the desert, Australia can further develop large high-quality biomass resources. Australia is best positioned to develop a large competitive bioenergy energy industry.

The importance of biomass in the carbon-constrained future is due to its unique features compared with other renewables:

- Biomass is the only renewable that can be used directly to generate green base-load electricity without the need of an energy storage system.
- Biomass is the only renewable that can be used directly to produce carbon-containing liquid fuels and chemicals that are currently produced from coal, natural gas and petroleum.
- Biomass is the only renewable that can be used directly to produce solid fuels, reductants and biocarbon materials that are currently produced from coal, natural gas and petroleum.
- Biomass is the only renewable that can be used to achieve negative emission while green products and services are provided, which is a cheap means for the world to avoid possible disastrous consequences of climate change.
- The use of biomass creates more local jobs in Australia than any other renewables and is the most effective means for regional development.

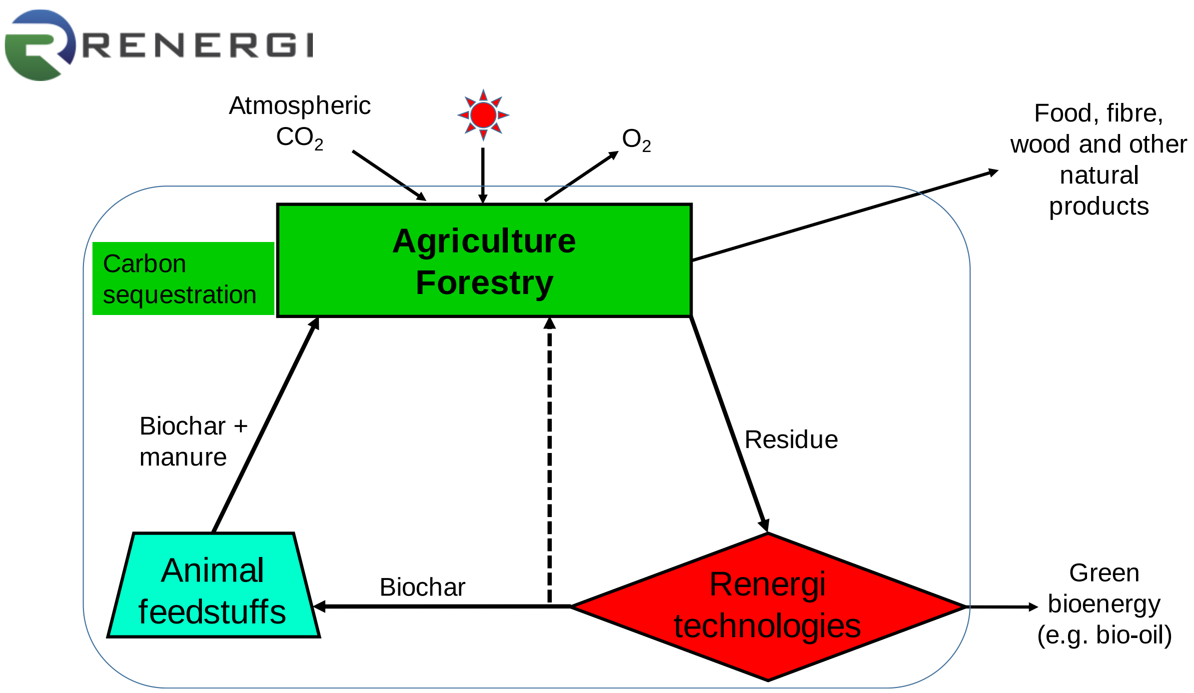

Figure 1. A schematic diagram showing the concept of negative-emission bio-based circular economy.

As the world transits to a sustainable development, the economy must transit to a circular one. As is schematically shown in Figure 1, biomass will play a pivotal role in the development of a negative-emission bio-based circular economy. This circular economy would represent a fundamental transformation of our agriculture, horticulture, forestry and related industry.

Presently, using atmospheric CO_2 and solar energy as the main inputs, the existing agriculture, horticulture and forestry mainly produce food, fibre, wood and other natural products to meet the essential requirement of our daily life. However, the clean utilisation of the residues from the agricultural, horticultural and forestry activities with advanced bioenergy technologies would establish a modern bioenergy industry. This new bioenergy industry will also meet a large portion of our energy and material demands, including liquid fuels, solid fuels, chemicals, solid reductants and speciality carbon materials that are currently manufactured from coal, petroleum and natural gas. Returning biochar into the soil would not only improve our soil productivity and sustainability, but also achieve negative emissions, permanently sequestrating atmospheric CO_2. Furthermore, biochar can also be part of animal feedstuffs, improving animal health and productivity while still eventually returning biochar back into the soil. Negative emission via biochar is among the cheapest means of removing CO_2 from the atmosphere.

This project aims to further develop and demonstrate a suite of low-emission biofuel technologies developed by the Curtin/Renergi researchers led by John Curtin Distinguished Professor Chun-Zhu Li. As is schematically depicted in Figure 2, the project consists of three

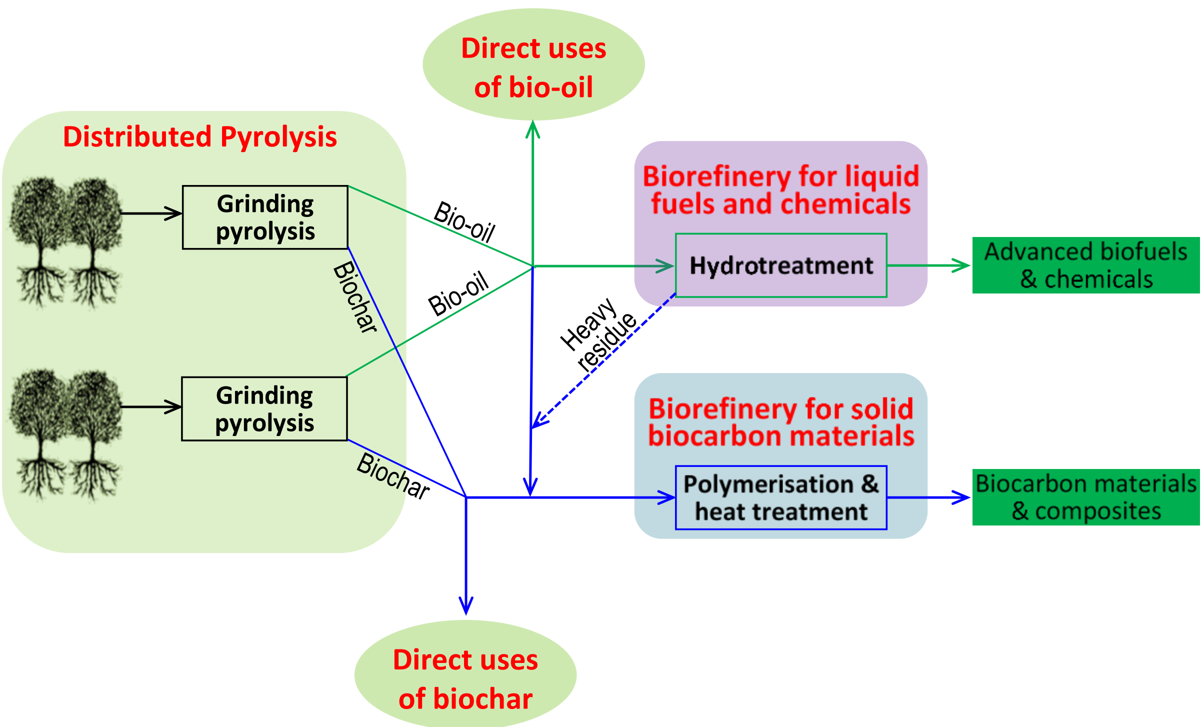

Figure 2. A schematic diagram showing the inter-relationship among three inter-related technology components in this project. “Direct uses” refer to the sale of bio-oil and biochar directly without any further refinery.

inter-related components.

- The first project component is the pyrolysis of biomass to produce biochar and bio-oil. In commercial operation, the pyrolysis of biomass will be carried out using pyrolysers distributed in the field close to the locations where biomass is grown. This arrangement of “distributed pyrolysis” (Figure 2) aims to reduce the costs to transport biomass over a long distance. The researchers in Curtin University have developed a patented pyrolysis technology, termed as “grinding pyrolysis” technology. The technology had been proven at a scale around 15 kg/hr of biomass processing capacity. This project aims to scale up this technology to 100 kg/hr of biomass processing capacity in order to obtain the necessary technical data and know-how for the design and operation of the first commercial scale (demonstration) pyrolyser.
- The second project component is the hydrotreatment of bio-oil to produce liquid biofuels and chemicals. This is a means of bio-oil refinery. The researchers in Curtin University had developed a proprietary technology for the hydrotreatment of bio-oil from the pyrolysis of biomass. This project aims to scale up this hydrotreatment (biorefinery) technology to 20 L/hr of bio-oil processing capacity in order to obtain the necessary technical information for the further scale up of this technology to a higher bio-oil processing capacity, e.g. around 200 – 1,000 L/hr, beyond this project.
- The third project component is the production of solid biocarbon materials from bio-oil and/or biochar. The researchers in Curtin University had developed a patented biocarbon technology and demonstrated the technology using bench-scale facilities. This project aims to further develop and demonstrate this technology to explore its practical uses. The biocarbon technology is another means of biorefinery, i.e. to upgrade bio-oil and biochar to high value solid fuels, reductants and specialty biocarbon materials.

Renergi places equal emphasis on two biorefinery routes shown in Figure 2. The need for liquid biofuels from non-food biomasses is well recognised globally. However, the transition from fossil fuels to renewables would also demand the manufacturing of solid fuels, reductants and specialty carbon materials (e.g. heavy duty electrodes used in steel and aluminium industry) from biomass. There is an urgent need for technology development in this area, where Renergi aims to be an industry leader.

The direct use of bio-oil and biochar (see Figure 2) is also very important. For example, bio-oil from our technology may be used directly as a liquid fuel according to the industry standard ASTM D7544 – 12 (2017). Furthermore, the use of biochar for carbon sequestration and soil amendment, e.g. following the International Biochar Initiative Biochar Standards, will become increasingly important as the world searches for ways to achieve negative emission (see Figure 1) in order to avoid the possible disastrous consequences of climate change.

Outcomes

Grinding Pyrolysis Technology

During this project, a 100 kg/hr demonstration plant based on the novel grinding pyrolysis technology has successfully been designed, built, commissioned and operated to investigate the pyrolysis behaviour of woody biomass and agricultural wastes grown in regional WA. A large number of trials have been carried out using the 100 kg/hr demonstration plant. Figure 3 shows the photos of typical biomass samples used.

Figure 4 shows a photo of the main parts of the 100 kg/hr grinding pyrolysis demonstration plant. The demonstration plant consists of a biomass drying system, a feeding system, a pyrolysis reactor, a bio-oil/biochar separation system, a bio-oil vapour condensation system, a non-condensable gas recycling system, a pressure relief system and a gas flaring system. Renergi's grinding pyrolysis has many important features as follows.

Figure 3. Photos of typical feedstocks used in the grinding pyrolysis trials. (a), mallee biomass; (b), wheat straw; and (c), pine wood.

Figure 4. A photo of Renergi's 100 kg/hr grinding pyrolysis demonstration plant in the Technology Park, Perth, WA.

A. Reduced feedstock preparation before pyrolysis. In Renergi's grinding pyrolysis technology, the grinding and pyrolysis of biomass take place simultaneously. It can accept mixtures of large (centimetre-sized or larger) and/or small (micron-sized) biomass particles in any proportion in the same feedstock. Biomass is fed into a rotating reactor that houses pre-heated grinding media (e.g. stainless steel balls). For small biomass particles, they will be heated up rapidly and pyrolysed as they come into contact with hot media. For large biomass particles, the external surface will be heated up rapidly to form a thin layer of biochar. The biochar has much better grindability than the raw biomass and thus the biochar layer will be ground away quickly to expose new surface. The next cycle of pyrolysis and grinding is then initiated on the newly exposed surface. Therefore, repeated simultaneous pyrolysis and grinding will achieve reasonably high particle heating rates even for large (centimetre-sized) biomass particles. The continuous fragmentation of pyrolysing biomass particles also speeds up the overall process.

This means that Renergi's technology practically grinds nascent biochar during pyrolysis. Due to the excellent grindability of the nascent biochar compared with that of the raw biomass, Renergi's technology is far more energy-efficient than competing technologies (e.g. fluidised-bed technologies) that require the feedstock biomass to be finely ground before the biomass can be fed into the reactor.

B. Production of biochar as fine particles. The necessary consequence of the simultaneous grinding and pyrolysis actions in Renergi's technology is that the biochar is always produced in fine particle sizes, e.g. mostly < 100 μm. This feature is particularly advantageous for certain applications of biochar. For example, the biochar product may be co-fired directly, with little further grinding, with coal in the coal-fired power plants or may be injected into the tuyeres of blast furnaces. The fine biochar particles from Renergi's technology are also similar in size and other properties to the natural biochar in the soil. Therefore, the biochar may be used directly for soil amendment.

C. Negligible need of carrier gas. Renergi's grinding pyrolysis technology eliminates the need of a large volume of carrier gas, which significantly reduces the capital and operating costs for the heating and cooling of carrier gas. The absence of a large amount of carrier gas also facilitates the condensation of bio-oil vapour to produce liquid bio-oil.

D. Oxidative pyrolysis. In addition to pyrolysis trials under the conventional pyrolysis conditions (i.e. in the absence of externally supplied air/oxygen), oxidative pyrolysis trials with a controlled amount of air supply were also carried out successfully. Oxidative pyrolysis would greatly help to improve the heat supply to the pyrolysis system, especially in future commercial operation.

This project has increased the technology readiness level (TRL) of the grinding pyrolysis technology from an overall TRL 5 to an overall TRL 7 with some aspects achieving TRL 8.

Bio-oil Hydrotreatment Technology

During this project, a 20 L/hr bio-oil hydrotreatment demonstration plant has been successfully designed, constructed, installed, commissioned and operated. Figure 5 shows the photos of some key parts of the 20 L/hr bio-oil hydrotreatment demonstration plant. The whole demonstration plant consists of the following sub-systems: a feeding system, a reactive distillation system, hydrotreatment reactors, a condensation-and-separation system and a gas flaring system.

Figure 5. Photos of Renergi's 20 L/hr bio-oil hydrotreatment demonstration plant in the Technology Park, Perth, WA. Upper left, hydrogen generator; lower left, hydrogen compressor; right, the main hydrotreatment plant.

Figure 6. Photos of typical biofuels produced from the hydrotreatment demonstration plant.

The liquid products from the hydrotreatment of bio-oil were normally separated into two phases under ambient conditions: an aqueous phase and an oil phase (biofuel). Depending on the extents of hydrotreatment, the biofuel products had colours ranging from almost colourless to dark brown: some examples are shown in Figure 6.

The biofuel samples were further separated by distillation. The distillate, e.g. with an upper boiling point temperature of approximately 200°C, was collected as petrol biofuel samples. The residue or the bottom product was collected as diesel biofuel samples. The detailed analyses of these biofuel samples indicate that the petrol biofuel samples had qualities mostly within the range of, or even better than, the quality required for commercial petrol and/or commercial ethanol E85. For example, the contents of sulphur, lead and phosphorus in the petrol biofuel samples were negligible or zero. The concentrations of regulated oxygenates such as methanol, ethanol, DIPE, MTBE and TBA were zero or very low in the petrol biofuel samples. The concentration of toxic benzene was also much lower than that in the commercial petrol. Furthermore, the petrol biofuel samples also showed excellent results during the copper strip corrosion tests.

The diesel biofuel samples also had a negligible content of sulphur. The concentrations of phosphorus and metals (Na, K, Ca and Mg) were also very low. Importantly, the diesel biofuel samples contained very low concentrations of polyaromatic hydrocarbons (PAHs), which cause health and environmental concerns when the commercial diesel is burned. The diesel biofuel samples also passed the copper corrosion test. Its physical properties such as density, viscosity, lubricity and flash point were also largely within the ranges for the commercial diesel and/or biodiesel.

The future Australian biofuel standards should consider the unique characteristics of biofuels. For example, the presence of oxygen-containing functional groups should be encouraged.

This project has increased the technology readiness level (TRL) of the hydrotreatment technology from TRL 5 to TRL 7 (overall) with some aspects reaching TRL8.

Biocarbon Technology

The essence of Renergi's biocarbon technology is the polymerisation of bio-oil (and biochar). A large number of chemicals have been screened for their possible uses as a polymerisation agent. Oxygen-containing compounds with unstable/unsaturated bonds may be good candidates for use as polymerisation agents. For example, furfural has an unsaturated furan ring and a carbonyl group, making it very reactive towards polymerisation. By using furfural as a polymerisation agent, the reactions between bio-oil and furfural or between furfural and bio-oil/biochar mixture at a relatively low temperature (e.g. <300°C) can turn the bio-oil liquid or the bio-oil/biochar slurry into a solid biocarbon polymer of very high mechanical strength. The biocarbon polymer can be further carbonised at high temperatures to improve its physicochemical properties.

The work in this project has found that bio-oil can be used as a binder for a wide variety of (reactive) materials to produce biocarbon composites.

The work in this project has also confirmed that the heavy bio-oil residue from the hydrotreatment of bio-oil can also be used in the production of biocarbon materials or biocarbon composites.

In addition to trials using bench-scale facilities, this project has also demonstrated the possibility to produce biocarbon materials or biocarbon composites semi-continuously.

Renergi's biocarbon and biocarbon composite technologies will find widespread applications in energy industry, chemical industry and metallurgical industry. Some examples may be cited here:

- ***Biocarbon reductants and specialty biocarbon materials for metallurgical industry***. Metallurgical coke from coking coal is an essential feedstock in metallurgical processes. With the increasing cost of metallurgical coke and the need to reduce CO_2 emissions, biomass has been reconsidered as the source to produce carbon reductants. Our carbonised biocarbon material has high densities and high carbon contents, representing a good possibility for use in the steelmaking process.

  Furthermore, the carbonised biocarbon materials made from bio-oil and furfural would contain almost no ash or sulphur. It can be potentially used to replace the petroleum pitch and/or coal tar pitch for manufacturing the heavy-duty carbon electrodes used in aluminium and steel production. Further research is required in the development of our technology for this particular application.

- ***Biocarbon composite technology for metallurgical industry***. Our trials have proved that bio-oil and biochar can be used to make a wide variety of biocarbon composites containing coke (charcoal) fines and minerals. The composites, with excellent mechanical strengths, may then become feedstocks to electric arc furnaces or blast furnaces.

Transferability

Renergi's grinding pyrolysis technology can accept many kinds of feedstocks. Renergi is currently exploring the use of its grinding pyrolysis technology in the waste management and valorisation. For example, municipal solid wastes may be pyrolysed to produce a (bio)char and a pyrolysis (bio-)oil. While the waste plastics in the municipal solid wastes present a major difficulty for many other means of waste management and valorisation, the waste plastics co-mingled/mixed with other components in the wastes would be easily pyrolysed to produce a liquid oil and a small amount of char. When biochar is returned to soil, the overall process would achieve negative emission: about 0.6 tonnes of CO_2-e can be sequestrated for every tonne of municipal solid waste to be pyrolysed, depending on the exact composition of municipal solid wastes.

Renergi's hydrotreatment technology can also be applied to the hydrotreatment of other bio-crudes, e.g. from the hydrothermal liquefaction of biomass.

Renergi's hydrotreatment technology may also use the hydrogen from the hydrolysis of water using electricity generated from the intermittent renewables such as solar and wind. This may represent an efficient means of energy storage.

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Intellectual property: patents / licences

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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

The project has successfully scaled up Renergi's grinding pyrolysis technology to a biomass processing capacity of 100 kg/hr and scaled up Renergi's hydrotreatment technology to a bio-oil processing capacity of 20 L/hr. The project has also successfully further developed and demonstrated Renergi's biocarbon and biocarbon composite technologies for the production of various biocarbon materials and biocarbon composites using bio-oil and biochar as part of the feedstocks. This project has created a large amount of commercially valuable intellectual property, including patents and technical know-how.

Various knowledge sharing activities have also been carried out to disseminate the outcomes of this project to governments, industry, investors and researchers.

This project has now been successfully completed and achieved all of its objectives. Renergi has formulated a comprehensive strategy to commercialise the technologies developed and demonstrated in this project. The successful commercialisation of these technologies 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.

Lessons Learnt

Lessons learnt report: hydrogen safety

Project Name: *A Low Emission Biofuel Technology*

Knowledge Category:	Logistical
Knowledge Type:	Operation and maintenance
Technology Type:	Bioenergy
State/Territory:	WA

Key learning

This project has required the use of large amounts of hydrogen to carry out the hydrotreatment of bio-oil in a demonstration plant. The concern about hydrogen safety has been a significant factor in deciding the means of hydrogen supply for the hydrotreatment trials.

Implications for future projects

Hydrogen supply should be an important consideration in the practical plan of a large R&D project involving the use of large amounts of hydrogen.

Knowledge gap

The potential safety issues involved in the storage of hydrogen should not be underestimated.

Background

Objectives or project requirements

The hydrotreatment of bio-oil is an important part of this project. A large amount of hydrogen is required to carry out a hydrotreatment trial in a demonstration plant. Common hydrogen cylinders for general laboratory use would no longer be adequate. An alternative means of hydrogen supply is required.

Process undertaken

At the beginning of this project, two options of hydrogen supply were investigated: bulk storage using large hydrogen trailers and on-site hydrogen generation.

For the first option, the use of hydrogen tube trailers would require less attention from the researchers in their operation so that the researchers can focus on the hydrotreatment itself. The hydrogen supply would be very stable. However, while the hydrogen trailers have been safely used worldwide, there can still be significant concern about the safety in storing large amounts of hydrogen in this way.

For the second option, an on-site hydrogen generator and a multi-stage compressor to produce high pressure hydrogen constitute a plant, which has to be operated continuously whenever a hydrotreatment trial is carried out. The researchers have to give significant attention to the operation of this hydrogen generator. However, a hydrogen generator contains very little hydrogen in the whole system during operation. Furthermore, no hydrogen is stored when the hydrogen generator is not in operation.

Finally, we decided to choose the second option by installing an on-site hydrogen generator.

Appendix

Keywords

Bioenergy; biomass; mallee; straw; grinding; pyrolysis; bio-oil; biochar; hydrotreatment; reactive distillation; biorefinery; biofuel; demonstration plant; biocarbon; biocarbon composite.

Glossary of terms and acronyms

The term “**biofuel**” is used here to refer to the liquid fuel obtained from the hydrotreatment of a bio-crude such as bio-oil, which in turn is produced from non-food lignocellulosic biomass. The term “biofuel” should not be confused with the term “biodiesel” that is commonly used to refer to the liquid fuel produced from a vegetable oil or animal fat, e.g. via the chemical reaction between lipids and an alcohol.