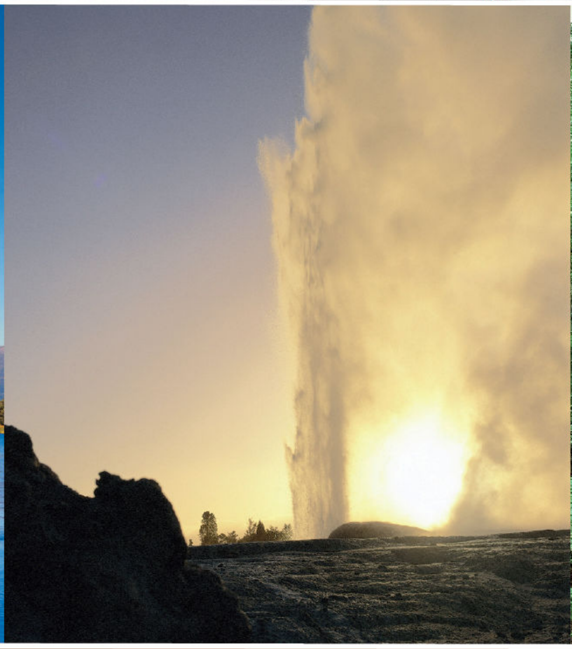
SCION
Next generation biomaterials

13 - 14 December 2010
Scion, Rotorua

SCIENCE SYMPOSIUM

Next Generation Liquid Biofuels and Co-Products



The attendance of international keynote speakers to the *Next Generation Liquid Biofuels and Co-Products* Science Symposium has been supported by MoRST and MFAT through the Science Promotion Fund.

Welcome

Welcome to Scion's Rotorua campus for the 2010 Science Symposium on Next Generation Liquid Biofuels and Co-Products.

Transportation biofuels and co-products derived from grasses, wood, and algae have significant potential to displace fossil-based fuels and chemicals in New Zealand. This Symposium will provide an important forum for the New Zealand biofuels research community to share their science, engage in scientific debate, and learn about international developments in these areas.

We expect this meeting to complement other fora with a policy or commercial focus to ensure that appropriate synergies between research and development activities are built and that our collective work remains both leading edge and relevant to the needs of New Zealand.

DAY ONE of the Symposium will showcase New Zealand biofuels research. In addition, the Ministry of Research, Science and Technology (MoRST) and the Ministry of Foreign Affairs and Trade (MFAT) have kindly supported the attendance of three international keynote speakers: Jack Saddler (University of British Columbia, Canada), Jim McMillan (National Renewable Energy Laboratory, United States of America), and Claus Felby (University of Copenhagen, Denmark).

DAY TWO of the Symposium will feature workshop sessions relevant to our biofuels research community. Discussion topics will include:

- What are the areas where New Zealand has obvious strengths?
- What are the science capabilities we should be developing in the future?
- What are the next steps for biofuels research in New Zealand?

The outcomes of these discussions will be summarised in a report and action plan which will be distributed to delegates and also to our research stakeholders.

We would like to acknowledge the team who have made this Symposium possible. The technical programme has been put together by the Scientific Organising Committee: Shusheng Pang (University of Canterbury), Rupert Craggs (National Institute of Water and Atmospheric Research), and Michael Jack (Scion). For finance, graphics, communications, and other administrative support, we would like to thank Scion staff Michelle McFarlane, Lesley Caudwell, Karen Shaw, Christl McMillan, Jane Hope, Paul Charteris, John Smith, Richard Moberly, Sarah Davies, and Ruth Falshaw. Finally, we acknowledge the speakers, poster presenters, and session chairs for the important contribution they will make during the Symposium.

The success of the Symposium depends on your support and participation. The high level of interest (75 registrations and 40 submitted abstracts) demonstrates the demand for this type of event and we hope the Symposium is the start of an on-going series of collaborative interactions.

We look forward to an exciting and stimulating programme and hope you enjoy the Symposium and your visit to Rotorua.

Trevor Stuthridge
Michael Jack
Katharine Challis

Contents

General Information

Venue
The Symposium sessions will be held in Scion's Rimu Room.

Catering
Morning and afternoon tea, lunch, and the poster session will be held in the Scion Café, located adjacent to the Rimu Room. Food and drink, other than water, is not permitted in the Rimu room. Please consume these items prior to returning to the Symposium sessions.

Symposium Dinner
The Symposium dinner is scheduled for 7.00 pm on Monday and will be held at Skyline Rotorua, 185 Fairy Springs Road. There will be a cash bar operating. A bus service has been arranged for transport there and back. The bus to Skyline Rotorua will depart from outside Scion reception at 6.15 pm. After dinner, the bus will depart from Skyline Rotorua at 9.30 pm. The bus will return to Scion via Ventura Inn and Suites, Hotel Ibis, and Lakeside Novotel, as required. You are welcome to leave luggage on the bus during dinner. If you have your own transport to the Symposium dinner, when you arrive at Skyline Rotorua please say that you are with Scion.

Speaker Information
A projector will be available for use during your presentation and presentation slides emailed to us prior to the Symposium will be accessible on our system. If we do not already have a copy of your presentation, you can upload your presentation using a memory stick or via a web-based email client. To arrange this please contact one of the organisers prior to your session. The preferred presentation format is Microsoft Office 2007, although Microsoft Office 2003 files are also supported. If your presentation has been composed on a Macintosh and is not in a Microsoft-compatible format, please contact one of the organisers immediately.

Poster Presentations
There are 26 posters confirmed on the Symposium programme. You are welcome to mount your poster at any time on Monday at your convenience prior to the poster session at 4.00 pm. Your poster number can be found in the Poster Abstracts section of this programme and will be posted for you on your assigned display board. The poster display boards are 2.3 m high x 1.2 m wide. Please make sure your poster does not hang over the sides of the board. Pins, staples, and Velcro® can be used to mount your poster, but please do not use Blu-Tack®. We have a supply of pins available. Please remove your poster as soon as possible once the Symposium closes on Tuesday afternoon.

Symposium Report
After the Symposium, a report and action plan will be prepared which will be distributed to delegates and also to our research stakeholders. Please contact one of the organisers if you would like to be involved in preparing this report. The Scientific Organising Committee will review the final version.

Map of Research Interests
To provide further information for the Symposium report, we have included in your registration pack a brief questionnaire on your research interests. Please complete this questionnaire and leave it in the tray provided at the back of the Rimu Room before the end of the Symposium.

General Information

Event Feedback Form

We value your feedback and would be grateful if you would share with us your thoughts on the Symposium. Please complete the feedback form provided in your registration pack and leave it face down in the tray provided at the back of the Rimu Room before the end of the Symposium.

Name Badge Holders

We would be grateful if you would leave your name badge holder in the box provided at the back of the Rimu Room before the end of the Symposium.

Abstracts

Abstracts included in this programme are as supplied by authors. Contact addresses are in New Zealand unless otherwise specified.

Scion Tour

A Scion tour will be conducted for delegates at the end of the Symposium. The tour will include the New Zealand Lignocellulosic Bioethanol Initiative pilot plant, the Waste 2 Gold process lab, and bioplastics research facilities. To join the tour, please meet in the Scion Café at 2.00 pm on Tuesday.

Programme Summary

Technical Meeting: Monday 13 December

8.00 am Registration

8.30 am Whakatau (Informal Welcome)

8.45 am Tea and coffee

9.15 am Introduction: **Trevor Stuthridge**, Scion

SESSION ONE
Chair: **Ralph Sims**, Massey University

9.25 am **Jack Saddler**
University of British Columbia, Canada
Task Leader of IEA Bioenergy Task 39
The biorefining story: progress in the commercialization of biomass-to-ethanol

10.10 am Morning tea

10.30 am **Jim McMillan**
National Renewable Energy Laboratory, United States of America
Cellulosic biofuels in the USA: progress and new initiatives

11.15 am **Claus Felby**
University of Copenhagen, Denmark
Development of large scale cellulosic ethanol – from nano meter to square kilometre

12.00 noon Lunch

SESSION TWO
Chair: **Manfred Woergetter**, FJ-BLT Wieselburg and Bioenergy2020+, Austria

1.00 pm **Shusheng Pang**
University of Canterbury
Biomass to hydrogen-rich syngas and liquid fuels through thermochemical processing

1.20 pm **Yukinori Iwasaki**
CRL Energy Limited
Testing of biomass/lignite blends for co-gasification

1.40 pm **Rupert Craggs**
National Institute of Water and Atmospheric Research
NIWA's wastewater algae biofuels research

2.00 pm **Owen Catchpole**
Industrial Research Limited
Fermentation of lipid-bearing micro-organisms with downstream extraction and processing using supercritical fluids to produce high value lipids and biofuels

2.20 pm Afternoon tea

SESSION THREE
Chair: **Hugh Morgan**, University of Waikato

2.40 pm **Ian Suckling**
Scion
Softwoods for biofuel production: a New Zealand solution

3.00 pm **Line Haaning**
University of Waikato
Characterisation of lignocellulose-degrading enzymes from the ruminant bacterium Butyrivibrio proteoclasticus

3.20 pm **Richard Scott**
AgResearch Grasslands Research Centre
In planta *production of enzymes for use in the preparation of biofuel feedstocks*

3.40 pm **Michael Jack**
Scion
Approaches to guiding biofuel technology selection and research priorities

4.00 pm **Poster session**

6.00 pm Close of Technical Meeting

7.00 pm Symposium dinner at Skyline Rotorua

Programme Summary

Workshop: Tuesday 14 December

8.30 am Introduction: **Trevor Stuthridge**, Scion

SESSION FOUR
Chair: **Trevor Stuthridge**, Scion

8.40 am **David Bull**
Parliamentary Commissioner for the Environment
Some biofuels are better than others: thinking strategically about biofuels

9.00 am **Brian Cox**
Bioenergy Association of New Zealand
Towards a bioenergy strategy for New Zealand

9.20 am **Chris Mulcare**
New Zealand Trade and Enterprise
The clean economy – an opportunity to leverage our comparative advantages – an NZ and local regional perspective

WORKSHOP SESSION

9.40 am New Zealand's current research, strengths and weaknesses

10.10 am Morning tea

10.30 am New Zealand research directions and opportunities

11.30 am Next steps

12.10 pm Conclusion: **Trevor Stuthridge**, Scion

12.20 pm Lunch

1.20 pm Close of Workshop

Keynote Presentations

Biography

Dr. John (Jack) Saddler is the endowed Professor of Forest Products Biotechnology / Bioenergy (originally an NSERC Industry Chair) and also the former Dean, Faculty of Forestry at the University of British Columbia.

As a senior and seasoned research scientist, Dr. Saddler has been involved, for more than 30 years, in various national and international organizations that have advanced the global understanding of how woody biomass can be converted to useful fuels and chemicals. He is a Fellow of the Royal Society of Canada, Canada's highest recognition for scientists, and he has received many other awards such as the International Union of Forest Research Organizations (IUFRO's) Scientific Achievement Award, the Charles D. Scott award for contributions to the field of "Biotechnology for fuels and Chemicals", etc. Recently, Dr. Saddler received the prestigious 2009 Leadership award, presented from Life Sciences British Columbia for demonstrated leadership in the industry and given to individuals who have assisted in the creation and advancement of the broader life sciences communities over time.

Dr. Saddler has published more than 300 papers, several books, holds several patents and is a regular reviewer/advisor for agencies such as the US Dept of Energy, USDA, NSERC, World Bank, etc.

Outside of the research setting, Dr. Saddler has not only advised policymakers at the highest levels provincially and nationally, but has been instrumental in the creation of long-standing initiatives to demonstrate, commercialize and transfer promising biorefining technologies, such as the creation of Ethanol BC and the BC Bioenergy Network. Nationally, his influence extends to such bodies as the Science Directorate of the Canadian Forest Service, the Canadian Council of Forests Ministers, and the National Roundtable on Economy and Environment. Internationally, he has contributed significantly to the work of the UN's Food and Agricultural Organization (FAO), the US DoE, USDA, the International Energy Agency (IEA) Paris, and he has acted as the Task Leader of the Liquid Biofuels network of IEA Bioenergy organization.

Abstract

John N Saddler*, Jana Hanova*, and Warren E. Mabee**
*Forest Products Biotechnology/Bienergy Group, IEA Bioenergy Task 39, University of British Columbia, 2424 Main Mall, Vancouver BC V6T 1Z4, CANADA, **Queen's University, 423-138 Union Street, Kingston, Ontario, CANADA K7L 3N6
The biorefining story: progress in the commercialization of biomass-to-ethanol

Continued insecurity around oil supplies has helped to keep oil prices high, thus causing a rapid expansion in global bioethanol and biodiesel production. Interest in utilizing lignocellulose for the production of a 2nd generation of biofuels has grown significantly. Technologies from the agricultural sector may be combined with recent technical improvements that have made wood-based bioconversion more feasible. The biorefinery concept has been proposed as a means to extract maximum value from lignocellulosics, of which only a portion of the chemical structure is suitable for biofuel production. The continued development of new conversion technologies will allow these biorefineries to utilize lignocellulosic feedstocks, enabling the production of additional value-added bioproducts and more efficient recovery of bioenergy. There are a number of complementary platforms for processing lignocellulosic feedstocks, including traditional platforms (i.e. existing pulping technologies) as well as emerging technologies that are biological-based or thermochemical-based. There is no clear candidate for "best technology pathway" between the competing biochemical and thermo-chemical routes and monitoring of large-scale demonstration projects is essential to provide accurate comparative data. Even at higher oil prices, 2nd-generation biofuels will

probably not become fully commercial nor enter the market for several years to come without significant government support. Considerably more investment in research, development, demonstration and deployment is needed to ensure that future production of the various biomass feedstocks can be undertaken sustainably and that the preferred conversion technologies are identified and proven to be viable. The expertise, progress and goals of the members countries and companies involved with IEA Bioenergy Task 39 will be used to descibe the progress in the biorefining area and our attempts to commercialise advanced biofuels.

Biography

James D. ("Jim") McMillan is the group manager for Biochemical Refining Process R&D and a principal research engineer in the National Renewable Energy Laboratory's Bioenergy Center, where he helps to advance lignocellulose biorefining technologies. His is the co-inventor on 2 patents, co-recipient of 2 R&D 100 awards, and author or co-author of 6 book chapters, more than 60 technical papers and reports, and more than 100 posters and presentations. He co-leads, with Jack Saddler, the International Energy Agency's Bioenergy Task 39 focused on advancing liquid biofuels (www.Task39.org) and also co-chairs the annual Symposium on Biotechnology for Fuels and Chemicals. Jim is an associate editor for the open access journal *Biotechnology for Biofuels* as well as a reviewer for several other journals and funding agencies. He is also a member of the American Chemical Society and the American Institute of Chemical Engineers (AIChE), where as a former elected director of the Food, Pharmaceutical, and Bioengineering Division he helped to grow AIChE's biorefinery-related programming (which has since become part of AIChE's Sustainable Engineering Forum). Jim has served on numerous doctoral and masters students' theses committees, and he is or has been an adjunct faculty member in the Colorado State University, University of Colorado, and University of Puerto Rico chemical engineering departments. He obtained his B.S. in chemical engineering with high distinction from Colorado State University and his M.S. in chemical engineering practice and Ph.D. in biochemical engineering from the Massachusetts Institute of Technology.

Abstract

James D. McMillan
National Bioenergy Center, National Renewable Energy Laboratory, MS 3511, 1617 Cole Boulevard, Golden, CO 80401-3351, United States of America

Cellulosic biofuels in the USA: progress and new initiatives

A tremendous amount of work is underway in the United States of America, at NREL and elsewhere, to develop and demonstrate cost competitive process technologies to produce liquid fuels from non-food lignocellulosic woody and herbaceous plant materials ("cellulosic biomass"). A variety of technologies have been demonstrated to be technically feasible for producing such so-called advanced biofuels, including those based on primarily biochemical or thermochemical conversion as well as those based on hybrid concepts employing a combination of biochemical and thermochemical processing steps. Many processes are under active development to demonstrate the ability to consistently achieve technical and economic performance targets at commercially relevant scale.

This presentation will describe recent progress on advanced biofuels research and development in the USA. Efforts to demonstrate cost-competitive biochemical and thermochemical refining technologies will be discussed. Recent progress achieved at NREL to reduce the cost of converting cellulosic biomass to ethanol or mixed alcohols will be highlighted, as will new initiatives to convert biomass derived sugars, synthesis gases and pyrolysis liquids to advanced biofuels. Remaining technical barriers and as-yet unrealized opportunities to stimulate the commercialization of biofuels-oriented biorefineries also will be reviewed. Although capital and operating costs remain high for biofuels production from cellulosic feedstocks compared to production from grain (corn, wheat) or sugar (beet, cane), the gap in economic feasibility between conventional and advanced biofuels technologies continues to diminish and early efforts to commercialize leading processing routes are beginning.

Biography

Claus Felby is professor of biomass and bioenergy at University of Copenhagen. He has worked with biomass and biotechnology for more than 15 years within both private industry and academia. During his PhD he worked closely with the biotech industry and worked as a research chemist before returning to academia in 2001. He has extensive knowledge within basic and applied biomass science and has coordinated and managed national and international projects within the area. His current research group has a close collaboration with several academic and industry partners within the bioenergy and biomass area. Currently he is heading the Fuel for Life strategic research area on bioenergy at the Faculty of Life Sciences, University of Copenhagen.

Abstract

Claus Felby
University of Copenhagen, Rolighedsvej 23, 1958 Frederiksberg, Denmark
Development of large scale cellulosic ethanol – from nano meter to square kilometer

Since 2004 there has been an intensive devolepment of commercial scale straw based cellulosic ethanol in Denmark. In October 2010 gasoline with 5% straw based ethanol became available at gas stations all over Denmark. The straw to ethanol proces is running at high dry matter levels and is based on hot water and enzymes only. This presentation will describe the technical development and the scientific findings along with the integration between existing heat and power plants and the ethanol production unit.

The commercial scale development has also made it possible to analyse the impact of introducing large scale cellulosic ethanol on the agricultural system. The results include energy, feed and land use balances and highlights that the ultimate constraint is not the technology efficiency but the land area that can be made available to the biomass supply. This also shows that the best environmental impact and reduction of GHG can be achieved if the biomass supply is based on existing agriculture and forestry.

Presentation Abstracts

Shusheng Pang
University of Canterbury, Private Bag 4800, Christchurch
Biomass to hydrogen-rich syngas and liquid fuels through thermochemical processing

Biomass gasification and pyrolysis have recently attracted great interests for development of sustainable bioenergy and liquid biofuels. This presentation will provide an overview on the latest research and development on the biomass gasification, biomass pyrolysis and biodiesel synthesis by Fischer-Tropsch undertaken at University of Canterbury, New Zealand.

The key issues in commercialization of biomass conversion technologies have been recognized as costs, conversion efficiency and environmental impacts. Therefore, extensive research has been conducted to reduce the costs, increase the conversion efficiency and reduce the negative environmental impacts. The research program undertaken at University of Canterbury has been focusing on development of a new gasification technology, called fast internal circulating fluidized bed (FICFB) gasifier with steam as gasification agent. So far, clean and hydrogen-rich syngas has been produced with the hydrogen content being up to 40% (vol.). With this gasification technology, optimum CO to H_2 ratio of 2 has been achieved for Fischer-Tropsch (F-T) synthesis of liquid fuel thus the research is also conducted to develop micro-channel F-T reactors and F-T catalyst. To reduce the transportation costs of widely distributed and low density biomass, co-gasification of biomass with coal and densification of the biomass by pyrolysis for gasification are being investigated. To improve the gasifier design and optimize the gasification operation, a cold transparent gasifier model has also been constructed and used for study of flow hydrodynamics in the FICFB gasifier.

Yukinori Iwasaki and Tana Levi
CRL Energy Limited, PO Box 31 244, Lower Hutt 5040
Testing of biomass/lignite blends for co-gasification

Coal gasification technology is receiving more interest as high-efficiency power generation technology coupled with CCS can reduce green house gases emission. Also, the effective utilisation of the biomass is in demand from the viewpoint of the global warming. Biomass is a renewable energy source as well as a carbon neutral resource. The emissions from the utilisation of biomass do not count as green house gas emissions. For these reasons, blended coal and biomass gasification is an attractive technology.

It is important to study the gasification reactivity of blended coal and biomass to improve the gasification technology and design of the gasification systems. In this study a bench-scale gasification unit was designed and commissioned. Two types of coal (lignite and sub-bituminous) and two types of biomass *Eucalyptus Nitens* and *Pinus Radiata* were chosen. The blends selected ranged from 0% biomass through to 100% biomass. The Blended coal and biomass char gasification reactivities at 850°C to 950°C were measured by analysing the syngas composition using a gas chromatograph analyser and were compared. The reactivities of lignite, *E. nitens* and blended lignite and *E. nitens* show higher reactivities than that of sub-bituminous and *P. radiata*.

Rupert Craggs
NIWA, PO Box 11-115, Hamilton
NIWA's wastewater algae biofuels research

NIWA's liquid biofuels research is centred on the niche area of biofuel conversion of algal biomass that is grown and harvested as a by-product of wastewater treatment using High Rate Algal Ponds (HRAP). Biofuel production from wastewater treatment HRAP algae provides an opportunity for distributed farm/community-level biofuels production, with the biofuel being used locally by the farm/community that produced it. HRAP provide energy efficient and cost-effective treatment of both municipal and agricultural (e.g. dairy, piggery and aquaculture) wastewaters. They are a significant improvement on conventional wastewater ponds, particularly in terms of efficiency and consistency of nutrient removal and disinfection of pathogenic bacteria and viruses. They also offer considerable benefits in terms of low energy wastewater treatment (with lower capital, operation and power costs) and lower GHG emissions compared with mechanical wastewater treatment plants.

This presentation will outline the main constraints for algal biofuel production that are overcome by combining wastewater treatment and biofuel production. Current research on specific issues of the wastewater to algae biofuel pathway will be discussed in particular (enhanced biomass production, reliable algal harvest, efficient conversion to biofuel, and other benefical co-products). Current collaboration and future opportunities for collaboration with other NZ researchers will be discussed.

O. Catchpole, J. Ryan, S. Tallon, E. Vagi, P. Dyer, and P. Hoefakker
Industrial Research Limited, PO Box 31-310, Lower Hutt
Fermentation of lipid-bearing micro-organisms with downstream extraction and processing using supercritical fluids to produce high value lipids and biofuels

Microorganisms that produce high levels of lipids are promising sources of both valuable polyunsaturated lipids, and lipids that are suitable for the production of biodiesel. IRL has been carrying out a program of research and development focussing on the production of lipids from micro-organisms including fermentation, extraction using supercritical fluids, and conversion of the lipid extracts to ethyl esters using chemical and enzymatic transformation technologies. Submerged liquid fermentation has been performed on a variety of microorganisms (both IRL collection and commercially available). Wet biomass has been extracted using the near-critical solvent dimethyl ether; and dry biomass using supercritical CO_2. The resultant lipid extracts have been partially converted to ethyl esters and simultaneously fractionated using a newly developed continuous enzymatic process in supercritical CO_2. Valuable polyunsaturated fatty acids are concentrated in a partial glyceride fraction, while fatty acid ethyl esters suitable for use as biofuel are collected as a second fraction.

Peter W. Hall, Michael W. Jack, John A. Lloyd, Karl D. Murton, Roger H. Newman, Trevor R. Stuthridge, **Ian D. Suckling**, Kirk M. Torr, Alankar A. Vaidya, and Mark S. Watton
Scion, Private Bag 3020, Rotorua 3046

Softwoods for biofuel production: a New Zealand solution

Conversion of plantation-grown softwoods to biofuels offers a potential solution to New Zealand's transport fuel requirements.

New Zealand currently has 1.8Mha of plantation forest, and 9.1Mha of hill country that is either marginal land or currently used for low to moderate productivity grazing. Our work indicates that 100% of New Zealand's road transport fuel requirements could be met by establishing forests purpose-grown for biofuel production on 2.5Mha of this marginal land. New Zealand's current plantation forest estate is predominantly *Pinus radiata* and this is also likely to be an important species for these future forests due to its proven performance in New Zealand.

Critical to realizing this possibility is an efficient and economically viable technology for converting softwoods such as *Pinus radiata* into fuels. An overview will be given of Scion's LBI (Lignocellulosic Biofuel Initiative) project, which aims to develop a cost-effective process for the enzymatic conversion of softwood into a sugar syrup plus a functional lignin. The sugar syrup can subsequently be processed into ethanol, butanol or other biofuels using technologies developed by other providers. Because of its unmodified structure, the lignin produced should be particularly suitable for conversion into bioplastics and other products as these markets develop. One of the key science challenges of the LBI project is to discover pretreatment conditions that maximize the sugar yield while minimizing enzyme dose.

Line L. Haaning*, Marisa Till, David Goldstone, Graeme T. Attwood, and Vickery L. Arcus
*Department of Biological Sciences, University of Waikato, Hamilton

Characterisation of lignocellulose-degrading enzymes from the ruminant bacterium Butyrivibrio proteoclasticus

The potential for lignocellulosic-based ethanol production is enormous. Despite being the most abundant renewable resource on the planet, currently only a small fraction of this resource is turned into biofuel[1]. The human need for efficient breakdown of lignocellulosic biomass for biofuel is relatively new. However, a great range of organisms have evolved to take advantage of the energy stored in plant material. The current trend, when converting biomass into fermentable sugars, is to use enzymes from a handful of model organisms. However, the lignocellulose depolymerisation process is diverse and increasing our knowledge of the various ways organisms achieve this, will offer opportunities to optimise biomass conversion for biofuel production[2].

Recently, Attwood and co-workers at Agresearch, sequenced the genome of the lignocelluloses degrading bacterium *Butyrivibrio proteoclasticus* first isolated from the rumen of New Zealand forage-fed cows[3,4]. All types of fibre-degrading activities need to be present to fully exploit the grass and therefore the bacterial species found in the fore-stomach of forage-fed ruminants could be a source of potentially useful enzymes for biofuel purposes. *B.proteoclasticus* expresses well over 150 enzymes involved in the depolymerisation of plant material. We have started to characterise a large number of these enzymes and I will be presenting the biochemical characterisation and 3D structures of a selected set of these. We will continue our work on this organism to increase the knowledge of available lignocellulose-degrading enzymes. Having a large and diverse set of enzymes to pick from, enables the industry to tailor-make enzyme cocktails with the right activities and stabilities for each specific biofuel feedstock.

References:

1: Pauly M. and Keegstra K. (2008) “Cell-wall carbohydrates and their modification as a resource for biofuels.” The Plant journal 54, 559-568.
2: Rubin E.M. (2008) “ Genomics of cellulosic biofuels” Nature reviews, vol 454.
3: Kelly WJ, Leahy SC, Altermann E, Yeoman CJ, Dunne JC, et al. (2010) “The Glycobiome of the Rumen Bacterium *Butyrivibrio proteoclasticus* B316T Highlights Adaptation to a Polysaccharide-Rich Environment.” PLoS ONE 5(8): e11942. doi:10.1371/journal.pone.0011942
4: Attwood, G. T. & Reilly, K. (1995) ”Identification of proteolytic rumen bacteria isolated from New Zealand cattle.” J. Appl Bacteriol 79, 22–29.

Joseph Bartho, Nick Roberts, Brent Barrett, and **Richard Scott**
AgResearch Grasslands Research Centre, Private Bag 11008, Palmerston North 4442
In planta *production of enzymes for use in the preparation of biofuel feedstocks*

One of the major costs in biofuel production is the enzymes required to convert the cellulose polymer in plant-based feedstocks into individual glucose units ready for subsequent conversion to ethanol or other forms of biofuels. Expression of recombinant cellulases in plants offers a means of producing the enzymes in a low maintenance, low cost organism, with little or no processing required prior to being added to the primary feedstock. We have successfully generated plants that express recombinant cellulases - standard commercially available CBHI and EGI from *Trichoderma reesei*, and two cellulases that were originally sourced from *Butyrivibrio proteoclasticus*, a bacteria found in the rumen.

Part of this program also evaluated various DNA sequences designed to target accumulation of the cellulases to specific subcellular compartments within the plants. Preliminary results from transient expression in tobacco leaves has shown that the different target/cellulase combinations were important in producing active cellulases. Also, the cellulases sourced from *B. proteoclasticus* possessed both endo and exocellulase activity and expression did not always relate to cellulase activity.

This presentation compares and discusses the results from the transient and stably transformed model plant species.

Michael W. Jack, M. Imroz Sohel, and Katharine J. Challis
Scion, Private Bag 3020, Rotorua 3046
Approaches to guiding biofuel technology selection and research priorities

A key challenge in biofuel production is to develop efficient conversion technologies that compete economically with fossil fuel production. As with other energy technologies, thermodynamic analysis provides a powerful tool for guiding technology selection and research efforts towards the development of more efficient biofuel production systems. We present some of our recent results from thermodynamic studies of the production of liquid biofuels from lignocellulosic biomass. These studies include: 1) an exergy analysis and comparison between a biochemical and thermochemical biofuel production process, 2) a thermodynamic analysis of geothermal energy integration into a biofuel production process, and 3) an exploration of the thermodynamic limits of biofuel production and opportunities for going beyond these limits.

David Bull
Parliamentary Commissioner for the Environment, PO Box 10-241, Wellington 6143
Some biofuels are better than others: thinking strategically about biofuels

Biofuels have the potential to make a real difference to New Zealand; to substantially reduce greenhouse gas emissions, improve fuel security, and make the economy cleaner and greener. However, the kinds of biomass currently being used as feedstock for biofuels in New Zealand cannot take us very far. And the biofuels currently being produced in New Zealand can only be used to supplement conventional petrol and diesel. It makes sense to focus on biofuel substitutes for diesel rather than substitutes for petrol. It makes no environmental sense at all, and indeed is unethical, for us to import 'bad' fuels made from feedstocks produced at the expense of rainforests and food production in the developing world. Producing drop-in biodiesels from wood seems likely to meet all these objectives.

Brian Cox
Bioenergy Association of New Zealand, PO Box 11 595, Wellington
Towards a bioenergy strategy for New Zealand

New Zealand has the opportunity for achieving additional value from existing forestry and new energy crops through the production of transport biofuels. The Bioenergy Association, in association with the NZ Forest Owners Association, has led the establishment of a NZ Bioenergy Strategy which has a vision of 30% of transport fuels coming from Bioenergy by 2040. This strategy provides a commonly agreed pathway to achievement of that vision. The next step is to establish agreed Implementation Plans that provide guidance for science and commercialisation programmes. In addition there is a need to identify approachs to be followed, gaps in capabilities and to provide clarity of who can contribute to research needs for the whole value chain from resource to use including conversion technologies.

Chris Mulcare
New Zealand Trade and Enterprise, PO Box 8680, Symonds Street, Auckland
The clean economy – an opportunity to leverage our comparative advantages – an NZ and local regional perspective

New Zealand has a unique opportunity to be a high value low carbon economy and a cleantech leader leveraging its abundant resources in renewable energy, biomass and agriculture as well as existing industrial infrastructure. This presentation will explore an accelerated pathway towards this and the Government's goal of $150Billion exports by 2025. In regards to biofuels development, Chris will discuss how New Zealand can buck the trend in the US and Europe and quickly move to scaleable drop-in renewable fuels. He will explore 6 success criteria for this and explore a range of opportunities for science providers to support industry and stay ahead of new low carbon industry development. A particular focus will be placed on specific regional opportunities – in particular turning Kawerau into a low carbon industry hub. Chris will discuss a project under development within NZTE to explore an "industrial symbiosis" closed loop economic development model for this.

Poster Abstracts

01

Tana Levi, Rod Brown, Michael Smith, Garth Williamson, and Yukinori Iwasaki
CRL Energy Limited, PO Box 31 244, Lower Hutt 5040
O_2 blown gasifier design

A new fluidized bed oxygen blown gasifier has been designed and is in the process of being constructed. The project was established as a proof of concept for coal/biomass co-gasification. The motivation of co-gasification is to combine New Zealand's limited resource of carbon-neutral biomass with our large, inexpensive, natural coal resources. This will improve energy security and provide a transition between fossil and plantation biomass technologies.

The new technology developed at CRL Energy Limited, in collaboration with IRL, comprises an oxygen blown co-fired gasifier with integrated electrolyser for production of low carbon footprint syngas, synfuels and Hydrogen. The 50 kW unit has the flexibility to operate on air or oxygen, with up to 50% biomass. The electrolyser system which supplies oxygen to the unit, also generates hydrogen which is then used to enrich the syngas to a consistently high quality.

02

Tana Levi, Rod Brown, and Yukinori Iwasaki
CRL Energy Limited, PO Box 31 244, Lower Hutt 5040
Pilot scale production of syngas from coal and biomass in a fluidized bed gasifier

New Zealand, in common with many countries, is faced with the issues of increased energy demand and the long-term environmentally sustainable production of energy to meet that demand. Currently it has decreasing gas reserves, well utilized hydro and geothermal resources, a significant and growing quantity of biomass and a developing wind energy resource. In some sectors the co-gasification of coal and woody biomass is increasing in interest. This has led to a 4 year research programme "Hydrogen and Clean Energy". The goal is to develop the technology platform, knowledge and expertise necessary to underpin the co-production of hydrogen and syngas. The results presented in this poster outlines some of the initial results.

03

T. P. Levi, Y. Iwasaki, and R. Brown
CRL Energy Limited, PO Box 31 244, Lower Hutt 5040
Design and operation of a miniature char gasification rig

Biomass and coal are important solid fuels to generate hydrogen-rich gas from steam gasification. To investigate the effect of coal-to-biomass ratios and the reaction kinetics for gasification of coal-biomass blends it was necessary to design and construct unique bench-scale experimental equipment.

The gasification agent selected was steam and the carrier gas was nitrogen. The apparatus was electrically heated in a furnace to temperatures up to 1000^{o}C. It was also necessary to preheat, cool, dry the gas at various stages as well as analyse the composition using gas chromatography. One of the most intriguing design challenges was the gasifier reactor. This is constructed entirely of glass and must support a char whilst allowing a free flow of gas. Specialist methodologies were also developed to produce suitable char pellets for the reactor.

04

Murray McCurdy, Michael Smith, and Phil Herrington
CRL Energy Limited, PO Box 31 244, Lower Hutt 5040
Fast pyrolysis of biomass

Fast pyrolysis is a thermo-chemical conversion method that can be used to produce fuels from biomass. The process converts the biomass into solid, liquid and gaseous fractions all of which contain some of the energy contained in the original biofuel. Fast pyrolysis particularly focuses on the formation of liquid products.

CRL Energy and OPUS International Consultants, in consultation with the University of Canterbury, have developed a fluidized bed fast pyrolysis rig to convert sawdust into solid and liquid products. This rig is being used to determine the processing parameters for the formation of biofuels, biochars and higher value products from woody biomass.

05

Michael Smith and Murray McCurdy
CRL Energy Limited, PO Box 31 244, Lower Hutt 5040
A continuous auger reactor for slow pyrolysis and torrefaction

A new pilot-scale test unit has been designed and constructed for the continuous, slow pyrolysis and torrefaction of biomass. The system is based around a screw conveyor which carries the feed material through an electrically heated reactor. The temperature profile along the length of the reactor can be controlled within the range 100-700°C, and is capable of carrying out drying, torrefaction and carbonization on a range of waste biomaterials from wood to sugarcane bagasse. These processes increase the energy density of the biomass and improve the grindability.

The unit is capable of producing over 5 kg/hr of liquid bio-oil for use as biofuels, and over 3 kg/hr of biochar for use as a solid fuel or as a soil enhancement and carbon sequestration material.

06

George Estcourt and Peter Hall
Scion, Private Bag 3020, Rotorua 3046
Torrefaction of woody biomass for energy densification and pre-treatment

Some common issues with using biomass as a fuel are; low energy density, geographically distributed, often far from urban centres where energy use is high, variable quality, composition, moisture and energy content. These properties lead to high costs and act as barriers in utilising biomass as a renewable energy option.

Torrefaction is a means of heat treating biomass, focussed on wood in this case, where there are multiple benefits including; energy densification, material stabilisation, improved fuel properties, improved processing properties, greater homogeneity (moisture content & energy value).

Scion developed a torrefaction test rig and conducted a series of tests at different temperatures and durations to determine the impact of torrefaction on matter loss, energy values, grindability and hydrophobicity of pinus radiata wood chip. Thermogravimetric analysis (TGA) was also used in the analysis

TGA data clearly revealed the impact of temperature and duration on the rate and degree of weight loss associated with torrefaction, with differing temperatures having substantial differences.

Temperature and duration of torrefaction also has varying impacts; increasing temperature and time increases matter loss but increases energy density, grindability and hydrophobicity.

07

Woei Saw, Ian Gilmour, and Shusheng Pang
Department of Chemical and Process Engineering, University of Canterbury

The influence of the bed height of the bubbling fluidised bed on the performance of a dual fluidised bed steam gasifier

A study was conducted in the 100 kW bubbling fluidised bed (BFB) dual fluidised bed steam gasifier to investigate the influence of the bed height on the producer gas composition, conversion efficiency and tar content. The bed height of the BFB was determined by a calculation based on the differential pressure measured across the BFB. The height of the BFB was increased from 0.45 to 0.85m by increasing the inventory of bed material in the gasifier from 12 to 18kg. In the experiments, inert greywacke river sand was used as the bed material and the gasification temperature was set at 730°C. During the gasification runs, the major compositions of the producer gas were measured using a micro-GC. The tars in the producer gas were sampled using a solid phase extraction (SPE) and then analysed using a Varian CP-3800 GC with a flame ionised detector (FID) technique. The key findings are: i) the influence of the bed height of the BFB on the producer gas compositions was insignificant and; ii) the carbon conversion and gasification efficiency increased by 45% and 20%, respectively, as the bed height of the BFB was increased from 0.45 to 0.85m; iii) conversely, the total tar concentration in the producer gas reduced by 30% as the bed height of the BFB was increased from 0.45 to 0.85m.

08

Woei Saw, Hamish McKinnon, Ian Gilmour, and Shusheng Pang
Department of Chemical and Process Engineering, University of Canterbury

Production of hydrogen-rich syngas from steam gasification of biosolids-wood blends using a dual fluidised bed gasifier

In New Zealand, approximately 240,000 dry tonnes of biosolids (dried sewage sludge) was produced in 2006, with approximately 50% being used for land reclamation, 35% to landfill and the rest being used in forest application and other uses (Ministry for the Environment, 2007). A new technology is required in order to maximise the energy recovery of the biosolids, which can potentially be a substitution of fossil fuel rather than for land reclamation or landfill. A study was undertaken at the University of Canterbury on steam gasification of mixtures of wood pellets and biosolids in a $100kW_{th}$ dual fluidised bed gasifier. Furthermore, a comparison of the syngas compositions of 100% biosolids of this study with previous studies which used air, O_2 and CO_2/N_2 as the gasification medium was conducted. The key findings of this study are: i) the syngas produced from the gasification of pure biosolids had higher content of H_2 (28%) compared with that from gasification of pure wood (23%), with the H_2 content increasing with biosolids fuel loadings; ii) the addition of 10 to 20% loading of biosolids in the fuel did not diminish the yields and the energy efficiency; and iii) the concentrations of H_2 and CO in the present study were found to be 40% higher than for those using other gasification agent.

09

Chris Penniall and Chris Williamson
Department of Chemical and Process Engineering, University of Canterbury, Christchurch

Small scale Fischer-Tropsch plants in New Zealand

Biofuel production via biomass gasification and Fischer-Tropsch (F-T) has been attracting extensive interests in the world. The challenge, however, is traditional F-T technology relies on very large scale plants for economic viability. Due to the geographical distribution and low density of the biomass feedstock, a shift to smaller plants is necessary while still producing fuel at a competitive unit cost. Two concepts are presented to address this need. Firstly the use of a combined heat, power and liquid fuels plant integrated into existing wood processing facilities. The availability of waste wood, and the requirement of electricity and heat for wood processing creates a synergy with a F-T based liquid fuels plant. The integration allows a simpler plant than traditional F-T while still achieving high overall efficiency. Using traditional reactor technology it is estimated F-T liquid can be produced for $US 150 per barrel.

The second concept for reducing scale yet keeping production costs competitive is the use of a microchannel reactor. Microchannel reactors have heat and mass transfer rates which are orders of magnitude better than traditional reactor technology. The result is smaller plant dimensions leading to lower capital cost as well as significantly better catalyst utilisation. Experimentation at the University of Canterbury has shown conversion per unit of catalyst several times better in a microchannel reactor compared to a fixed bed under the same conditions.

These two concepts have the potential to influence the competitive scale down of F-T technology and increase the suitability of the technology for the New Zealand biomass scenario.

10

Wayne Eltringham
Industrial Research Limited, PO Box 31-310, Lower Hutt

Hydrogen fuel gas production using high pressure water

There is a growing need to replace fossil fuels with renewable energy sources and biomass is gathering interest globally as a source of renewable energy, either from industry waste streams of from diversification of land use for specially grown crops. Processing with water at high temperatures and pressures offers promising opportunities for conversion of biomass into useful fuel gases. IRL has been carrying out a program of work to investigate this process. Glucose has been used as a model carbon source and has been converted to fuel gases using high pressure water (10.0 MPa at 573 K) with a Pt/Al_2O_3 catalyst in stirred tank and continuous-flow, tubular reactor systems. The gas mixtures are produced at positive pressure and the bulk gas product stream contains mainly hydrogen (≥30 %), CO_2 (~ 50 %) and CH_4 (~ 10 %), with the remainder being contaminant gases such as CO, ethylene, ethane, propylene and propane. The continuous flow methodology requires improvement and optimisation using `real-world' waste biomass samples. Supercritical water conditions without the use of a catalyst will also be investigated. Additional research will focus on downstream processing of the gas product stream and will include enrichment of hydrogen, and/or subsequent conversion of mixtures of hydrogen and carbon dioxide to dimethyl ether (DME), for use as either a green alternative to LPG, or as an extraction solvent for new supercritical processing technologies being developed by IRL.

11

Daniel van de Pas, Kirk Torr, and Roger Newman
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Epoxy resins from lignin-derived phenols

The production of lignocellulosic biofuels from biochemical routes will generate large amounts of lignin as a co-product. Epoxy resins can be made from lignin, either by adding glycidyl groups to the polymer or by breaking the polymer down to monomeric phenols and reconstructing the monomers into larger structures before adding glycidyl groups. Published examples of the latter route include the incorporation of vanillin, guaiacol or other monomeric phenols in spiroacetal or leucaurin structures, followed by condensation with epichlorohydrin to add at least two glycidyl groups to each molecule.

This presentation describes a novel example of the reconstructive route, in which monomeric phenols were incorporated in spirohydrindene structures. Guaiacol was condensed with acetone to give 6,6'-dihydroxy-5,5'-dimethoxy-3,3,3',3'-tetramethyl-bis-1,1'-spirohydrindene. This was then reacted with epichlorohydrin to make the diglycidyl ether which was formulated with a reactive diluent and cured with an amine cross-linking agent. Mechanical properties were determined and the results indicated that the resin could potentially be used as a substitute for conventional epoxy systems based on bisphenol A.

12

Kirk M. Torr*, Karen T. Love*, Stefan J. Hill*, Lloyd A. Donaldson*, and Bradley M. Holmes**
*Scion, Private Bag 3020, Rotorua 3046, ** Joint BioEnergy Institute, Deconstruction Division, Emeryville, CA, United States of America

Ionic liquid pretreatment of Pinus radiata *wood for biofuel production*

Softwoods are among the most recalcitrant of lignocellulosic biomasses targeted as feedstocks for liquid biofuel production. A severe pretreatment step is generally required for efficient enzymatic conversion of softwood cellulose and hemicelluloses into sugars for fermentation into biofuels. Ionic liquid pretreatment is a promising technology for enhancing enzymatic digestibility of lignocellulosic polysaccharides. In this study the impact of pretreating *Pinus radiata* wood with 1-ethyl-3-methylimidazolium acetate was investigated. The pretreatment involved heating ionic liquid/wood suspensions to partially solubilise the wood prior to adding water to precipitate the pretreated biomass. Hemicelluloses were preferentially extracted and the recovered wood was enriched in cellulose and lignin. Pretreatment significantly improved the enzymatic digestibility of the cellulose. Glucan was converted to glucose in yields of 80-93% in 24 hrs in pretreated wood compared to 9% in untreated wood. Analysis of the pretreated wood by solid-state NMR spectroscopy and scanning electron microscopy indicated that decreased cellulose crystallinity and increased surface area were contributing factors in improved cellulose digestibility.

13

J. S. McDonald-Wharry*, M. Merilyn Manley-Harris*, and J. A. Lloyd**
* University of Waikato, Hamilton, **Scion, Private Bag 3020, Rotorua 3046

Characterisation of water-soluble hemicellulose fragments produced during prehydrolysis of Pinus radiata *wood chips*

Hemicelluloses isolated from the prehydrolysis liquor of a hot-water prehydrolysis-kraft cook of radiata pine may have potential for later conversion into various products. However, their structure and molecular weight will be critical in determining their potential for further processing and suitability for use in various applications. This poster summarises some of our initial work in characterising the hemicelluloses in a hydrolysate from radiata pine.

Commercial radiata pine wood chips were treated with water using just a 90 minute ramp to 175°C in the prehydrolysis stage of a prehydrolysis-kraft cook. Approximately 40% of the hemicelluloses were extracted from the chips into the aqueous phase after thorough washing of the prehydrolysed chips. The solids in this aqueous extract were shown to be a mixture of wood resins, monomeric sugars, oligosaccharides, polysaccharides, lignin fragments and degraded carbohydrate material. Most of the non-carbohydrate material was removed from the concentrated water extract, before the oligosaccharides and polysaccharides were extracted using solvent precipitation techniques. These carbohydrates were then separated into different molecular weight fractions by size-exclusion chromatography. The isolated fractions were then analysed by MALDI-ToF mass spectrometry and NMR. The poster will describe some of the major polymer structures that were identified in the chip hydrolysate.

Such information is intended to be used in guiding future research into converting radiata pine hemicelluloses into potentially useful products which might include additives for the paper and textile industries, biofuels, emulsifiers, thickeners and stabilisers for food processing, hydrogels, or barrier coatings.

14

Alankar A. Vaidya and Roger H. Newman
Scion, Private Bag 3020, Rotorua 3046

Dose-response relationships in enzymatic saccharification of steam-exploded wood

In designing a process for saccharification of biomass, it is important to establish a balance between enzyme dose and incubation time. Enzymes can represent a substantial proportion of saccharification costs, while long incubation times require capital investment in stirred and heated tanks. A mathematical approach to optimisation becomes possible if the dose-response curves can be encapsulated as an algebraic relationship:

Conversion to sugars = Function(enzyme dose, incubation time)

Conversion efficiencies are relatively poor if the biomass is rich in lignin. A literature review pointed to three plausible mechanisms for lignin inhibition:

(i) Generalised non-productive binding of cellulase to lignin,

(ii) Relatively strong binding, of cellulase to lignin-rich residues,

(iii) Decreasing accessibility of cellulose as saccharification proceeds.

These ideas were tested by using a glucose analyser to obtain dose-response curves for *Pinus radiata* SEW at 5 incubation times, with 6 cellulase doses assessed for each curve. Results indicated that the first mechanism is of little concern, in that generalised binding is too weak to limit the final yield of glucose. The second might place upper limits on conversion, but more precise measurements will be required to test that possibility. The third mechanism, combined with fractal kinetics theory, led to an algebraic expression that gave a good fit to the 30 available data points.

15

Sylke H. Campion, Sara A. Carey, Sunita Jeram, John A. Lloyd, Katrina A. Martin, Roger H. Newman, Ian D. Suckling, Keryn L. Tutt, Alankar A. Vaidya, and Mark A. West
Scion, Private Bag 3020, Rotorua 3046

Methods for analysis of saccharification of lignocellulosics at Scion

The main aim of Scion's LBI (Lignocellulosic Biofuel Initiative) project, is to develop a cost-effective process for the enzymatic conversion of softwoods into a sugar syrup suitable for conversion into biofuels, biochemicals and biopolymers. For this we need reliable and quick analytical methods for the quantification of the starting biomass, pre-treated substrates, sugar syrup and saccharification residues. Here, we present the main analytical methods used at Scion to analyse these substrates.

Analysis of the solid substrates is carried out via methods commonly used for the analysis of wood and wood pulps. Briefly, the dried samples are first extracted with dichloromethane to remove the non-polar extractives. The levels of acid-insoluble and soluble lignin in the extracted substrates are determined following standard Tappi methods, and the levels of carbohydrates by ion chromatography (IC) analysis of the neutral wood sugars (arabinose, galactose, glucose, xylose and mannose) in the hydrolysates produced during the lignin determination.

The analysis of soluble sugars produced during saccharification is carried out in two ways. Initial screening is carried out by measuring the glucose released using a glucose analyser. This instrument provides a rapid screen (2 min/sample) and gives results which correlate closely with the reference IC method. Then, comprehensive monomeric sugar profiling of selected samples can be carried out by IC. The soluble oligomeric sugars can be determined by re-analysing the sugar syrup by IC following an acid hydrolysis.

16

James Strong and Tripti Singh
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Screening a New Zealand fungal collection for mannanase-producing isolates

Lignocellulosic biomass consists of cellulose, hemicellulose and lignin. Hemicelluloses are linear or branched heteropolysaccharides composed of all five monosaccharides commonly found in nature: d-xylose, d-galactose, d-mannose, d-glucose and l-arabinose. It is important that as much of the utilisable sugars are available to fermentative organisms in order to increase the potential of this material as a feedstock for ethanol production.

Mannnanase is a potentially useful enzyme for degrading hemicellulose into smaller units. β-mannanases are endo-acting hydrolases, attacking the internal glycosidic bonds of the mannan backbone chain, releasing short β -1,4-manno-oligosaccharides. In this study a collection of fungal isolates were screened for β-mannanase production. Promising isolates were then screened by comparing enzyme production in static and shake flask cultures.

The highest relative activities were generally obtained in the static cultures. One isolate, a *Penicillium* sp., was particularly promising. Not only did it produce the highest mannanase activities in both static and shake flask experiments, but the enzyme was produced the most rapidly – plateauing within 6 days when grown in the larger volumes.

17

H. W. Morgan, T. C. Williams, and H.-L. Sin
Thermophile Research Unit, University of Waikato, Hamilton

The gut microflora of the huhu grub

The Huhu grub (*Prionoplus reticularis*) feeds entirely on lignocelluloses until it pupates. We have examined the gut flora of grubs captured in the wild and cultivated in the laboratory on diets of untreated pine and cellulose. In addition, the frass from cultivated grubs has also been collected and examined by similar methods. We have used molecular techniques based on the 16SrDNA gene to catalogue the bacterial community members using conventional cloning and 454 sequencing protocols. The ITS spacer region has been used to catalogue the fungal component of the flora. Finally, we have used culture methods to isolate and describe the nitrogen-fixing bacteria present in the gut. Frass from cultivated grubs has been subjected to pyrolysis/GC and elemental analysis to determine alterations to lignocellulose substrates during digestion. In this presentation we will attempt to present an overview of the microflora involved in lignocelluloses utilisation and its response to changing diets.

18

M. Stott*, M.Sohel, X. Morgan*, and M. Jack**.**
*GNS Science, Wairakei, **Scion, Private Bag 3020, Rotorua 3046

Taking a thermophilic approach to biofuels production

The production of biofuels derived from second generation feedstocks is currently is not competitive when compared with the more established hydrocarbon-based fuels industry. Increasing the efficiency of cellulosic feedstock conversion is paramount if Biofuels use is to become more widespread. Where we present two thermophilic approaches in which GNS Science, Scion and collaborators are investigating to increase this efficiency and to establish a feasible biofuels industry in New Zealand.

Our first approach aims to increase the rate of cellulose hydrolysis via the use of cellulolytic enzymes sourced from thermophilic microorganisms. This programme of research has enriched and isolated a suite of novel cellulolytic and thermophilic bacterial strains from NZ geothermal systems including representatives from the phyla *Dictyoglomi*, *Thermus*, *Chloroflexi*, candidate division OP10, *Firmicutes* and *Proteobacteria*. So far, we have sequenced the genomes of two novel cellulolytic strains, have identified putative cellulolytic enzymes, and are in the process of characterising cellulolytic activity.

Our second approach is to investigate the feasibility coupling a biofuel production with a geothermal power. It is estimated that the conversion of steam to energy in a geothermal power station stands at as low as ~20%. The current practice is to couple the residual heat with a binary system, re-inject latent steam and/or use in non-associated industries. However, initial modelling indicates that up to an 80% conversion to useable energy is possible if biofuels production were coupled to geothermal power production. Here we present our initial modelling of an integrated biofuels and geothermal energy production facility.

19

Xochitl C. Morgan, Heike Anders, Matthew B. Stott
GNS Science, Wairakei

Insights into the diverse metabolic capabilities of candidatus "Thermogemmatispora" strain T81 via genome analysis

"Chloroflexi-like" strain T81 was isolated from geothermal soils in the Taupo Volcanic Zone [1], and is phylogenetically placed within the newly described genus Thermogemmatispora [2]. Strain T81 possesses a filamentous morphology with hyphaed mycelium and aerial spores. It is an aerobic, thermophilic and moderately acidophilic bacterium with broad substrate utilisation ability. In particular, this strain has a notable ability for the hydrolysis of almost all cellulosic and lignocellulosic compounds tested including cellulosic pulps with various lignin, hemicellulose and cellulose contents, crystalline cellulose, xylan and carboxymethylcellulose. In addition, this strain can utilise a suite of mono, di- and tri- saccharides as energy sources, as well as alcohols from methanol to pentanol and other complex nutrient media.

The genome of candidatus "Thermogemmatispora" strain T81 was recently sequenced and annotated. The genome is approximately 7.2Mb, and has a G+C content of 60.8%. It has approximately 5000 major ORFs. The annotation of the genome has identified more than 25 cellulolytic enzymes and a large array of genes involved in carbohydrate metabolism confirming its broad substrate utilisation. Of particular note were the identification of genes putatively involved in the hydrolysis of aromatic carbon compounds such as styrene and toluene. Here we discuss various aspects of the genome annotation and analysis, and we speculate the roles of aromatic carbon compound hydrolysis in lignin degradation.

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20

Felicito Gazo and Murray McCurdy
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Potential use of geothermal energy in New Zealand biofuel chains

New Zealand has both high- and low-enthalpy geothermal energy resources. High enthalpy geothermal energy resources systems are confined to the northern and central parts of the North Island, particularly in the Taupo Volcanic Zone (TVZ) of the Waikato and Bay of Plenty Regions and in Northland. Low enthalpy geothermal energy resources (<150°C) are mainly found in the northern half of the North Island, and in a band through the alpine areas of the South Island.

Currently, the largest and most significant industrial application of geothermal energy is in the pulp and paper, and timber processing developments at Kawerau. It is projected that the biomass energy industry will be a heavy user of geothermal heat in the future. There is also a big possibility that the use of geothermal heat can be extended and further useful applications found in the biofuels processing sector.

This study reviews the New Zealand biofuels sector, the processes, sector production, energy use, economics, and potential locations. It considers ways and means to introduce or increase the use of geothermal heat in the biofuel production chain and how best it can contribute in the improvement of its energy and environmental performance.

21

Garth Williamson and Murray McCurdy
CRL Energy Limited, PO Box 31 244, Lower Hutt 5040

Techno-economic analysis of biomass to liquids plant

One of the pathways for conversion of biomass into liquid fuels is through biomass gasification and then conversion of the syngas into diesel and petrol by Fischer Tropsch. This pathway has been studied to determine biofuel production costs over a range of production levels.

The study covered an oven-dry biomass input range from 2000 to 20,000 tonnes per day. The process included a biomass preparation step, including torrefaction, prior to gasification in an entrained flow gasifier. Following this there is a gas clean up step, Fischer-Tropsch reactor and product upgrading. The selectivity of the Fischer-Tropsch process was targeted towards the diesel fraction to maximise yield of liquid fuels.

The production cost per barrel of finished fuel, excluding the cost of biomass, was found to range from $30/barrel to $75/barrel depending on the parameters chosen.

22

M. Imroz Sohel and Michael W. Jack
Scion, Private Bag 3020, Rotorua 3046
Thermodynamic analysis of a lignocellulosic biorefinery based on a biochemical process

This paper presents an exergy analysis of a biochemical process for the production of bioethanol from a lignocellulosic feedstock. The major inefficiencies in the process are identified as: the combustion of lignin for process heat and power production, and the simultaneous scarification and fermentation process. As lignin is not converted to ethanol and lignin has a high chemical exergy, the overall efficiency of the biochemical process largely depends on how the lignin is utilized.

We also consider integrating geothermal heat into a biochemical lignocellulosic biorefinery to provide process heat. This enables the lignin-enriched residue to be used either as a feedstock for chemicals and materials or for on-site electricity generation. Our analysis shows that integrating geothermal heat into a biorefinery represents an improvement in overall resource utilization efficiency in both of the renewable energy sources.

23

Katharine J. Challis and Michael W. Jack
Scion, Private Bag 3020, Rotorua 3046
The fundamental efficiency limits of cellulosic biofuel production

Cellulosic biomass is a renewable source of chemical energy that can be converted into fuels and chemicals. In a perfectly efficient conversion process, the potential of the biomass to do chemical work is entirely retained in the chemical fuel and co-products. However, there are inevitably both practical and theoretical inefficiencies. The aim of this work is to consider the fundamental chemical processes that take place during the conversion of cellulosic biomass to liquid biofuels and determine the ultimate theoretical limits on the thermodynamic efficiency of biofuel production.

There are different methods for extracting work during a chemical reaction and not all are equally efficient. For example, a fuel cell converts chemical energy into electrical energy with a theoretical efficiency of 100%. Living systems use enzymes to make efficient use of their energy resources by coupling energy-yielding and energy-requiring processes. In biofuel production processes, work is usually only extracted during chemical reactions by recovering the heat of reaction. This is fundamentally inefficient and places a theoretical limit on the efficiency of biofuel production. We determine this theoretical limit for a variety of different biofuel production pathways. Our approach enables an idealised comparison to be made between different biofuel production pathways and highlights the need for technological approaches that go beyond heat recovery to use chemical energy more efficiently.

24

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Metal biosorption studies in lignocellulosic biorefinery effluent to enhance water re-use

Biosorption of metals by micro-organisms is a promising technology to remove accumulated non-process elements in highly recycled biorefinery process water. Removal of such element would enable greater water reuse, enhancing the sustainability of the biofuel. To explore this technology, a model organism was needed that will grow in wastewater from a lignocellulosic biorefinery effluent and take up metals. Bacteria, algae, yeast and fungi from existing collections and those isolated from pulp mill wastewater were considered. Organisms were tested in a model lignocellulosic ethanol biorefinery wastewater spiked with manganese and zinc (0.2 mM), undesirable metals anticipated to accumulate in highly recycled process water. The model wastewater contained high loading of dissolved organic matter (900 mg/L) from pulp mill effluent, which will also compete for binding of the metals. Organisms that grew best in the model wastewater were isolated from pulp mill wastewater bioreactors, verses other sources. Metal uptake varied significantly by species. A bacterium, *Novosphingobium nitrogenifigens* Y88^{T}, removed the most metal per unit biomass, 33 mg Zn/g biomass and 16 mg Mn/g biomass. A yeast isolated from another wastewater reactor, *Candida tropicalis*, produced the most biomass and removed the most total metal, 38% of Zn, while uptake per unit biomass was 24 mg Zn/g. No other species removed significant amounts of Mn. These results indicate that micoorganisms can remove significant amounts of metals in wastewater with high concentrations of dissolved organic matter. Metal biosorption may be able to extend water re-use and therefore lower the water footprint of future biorefineries.

25

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The freshwater footprint of a potential wood to ethanol supply chain in New Zealand: methodological aspects and first results.

Blending ethanol with gasoline has been identified as a strategically important biofuel option for New Zealand (Wright, 2010). There are several potential sources of ethanol; one is from fermented forestry biomass. Prior studies on ethanol production from a plant biomass identified freshwater use as a significant issue (e.g. Fingerman et al., 2010, Dominguez-Faus et al., 2009, Gerbens-Leenes et al., 2009).

A life cycle assessment (LCA) study was carried out by Scion, which aimed to assess a potential wood to ethanol supply chain used to make 10% ethanol blended diesel. Two methods to quantify freshwater use were implemented; a measurement based on the volume of freshwater and an assessment of the impact of that freshwater use.

The first results from this study indicate that there is a substantial difference between the volumetric (126 kg/vehicle km) and impact assessment (0.02 kg ecosys. H_2O-equiv/vehicle km) approaches. This suggests that, whilst the freshwater use of a wood to ethanol supply chain is likely to be large, the impact of this water use may be minimal.

However several methodological aspects need to be addressed before decisions are made using footprint information. Indeed, an improvement in the underlying data, accurate characterisation of freshwater use, and a harmonisation of approaches is crucial. Furthermore, expanding the impact categories studied and integrating LCA data with other decision support criteria is necessary.

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26

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Status of 2nd generation biofuels demonstration facilities
A report to IEA Bioenergy Task 39

Driven by the need to replace fossil transport fuels at highest possible GHG mitigation considerations without social conflicts, large efforts are dedicated to the development of technologies for the production of biofuels from lignocellulosic raw materials worldwide. A high number of projects are being pursued, but only few facilities in the demonstration scale are actually operating. During the past IEA Bioenergy Task 39 period task delegates from 15 countries and the delegates to IEA Bioenergy Task 33 were asked to list 2nd generation biofuel projects in their countries and so produced a list of >150 projects. The respective project owners were then asked to provide detailed information, such as type of product, type of conversion technology, production capacity, current status of the project, project owner and location. Sound data could be collected for 66 projects that are being pursued currently, and details on the facility size, feedstock in use and technology applied could be provided. Many facilities in the demonstration scale are under construction and will hopefully successfully demonstrate biofuels production from lignocellulosic raw materials in the near future. Plans exist to build larger commercial facilities and thus rapidly increase the production capacities. Despite the possibly fast development, the volumes of lignocellulosic biofuels to be produced in the next five years will be small as compared to the current production of conventional biofuels. High efforts still need to be made to pursue these and more demonstration activities and to quickly multiply facilities when technologies have proven their technical and economic feasibility.

While the contribution to the SCION Conference will give an overview on the status by mid 2010, all data on these projects is also available in the internet (http://biofuels.abcenergy.at/demoplants/) and will be updated and expanded to new projects throughout the years to come.