R&D Activities on Biomass Gasification for Syngas and Liquid Fuels at the University of Canterbury

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Outlines

- Introduction
  - Resources of biomass
  - Biomass energy conversion technologies
  - Key issues in commercialisation of the biomass energy technologies
- Research activities and achievements at University of Canterbury on biomass energy:
  - BTSL programme and Objectives
  - Recent progresses
- Opportunities and challenges

Introduction

New Zealand has abundant resources of biomass from forestry and wood industry

▼Available wood processing residues (after other uses): 1.5-4 million m^3 p.a. from 2007 to 2027.

▲Collectable forest residues: 2-6 million m^3 p.a. from 2007 to 2040.

New Zealand also abundant biomass resources from Agricultural residues

About 1 million oven-dry tonnes p.a. from wheat, barley, oats, maize grain etc.

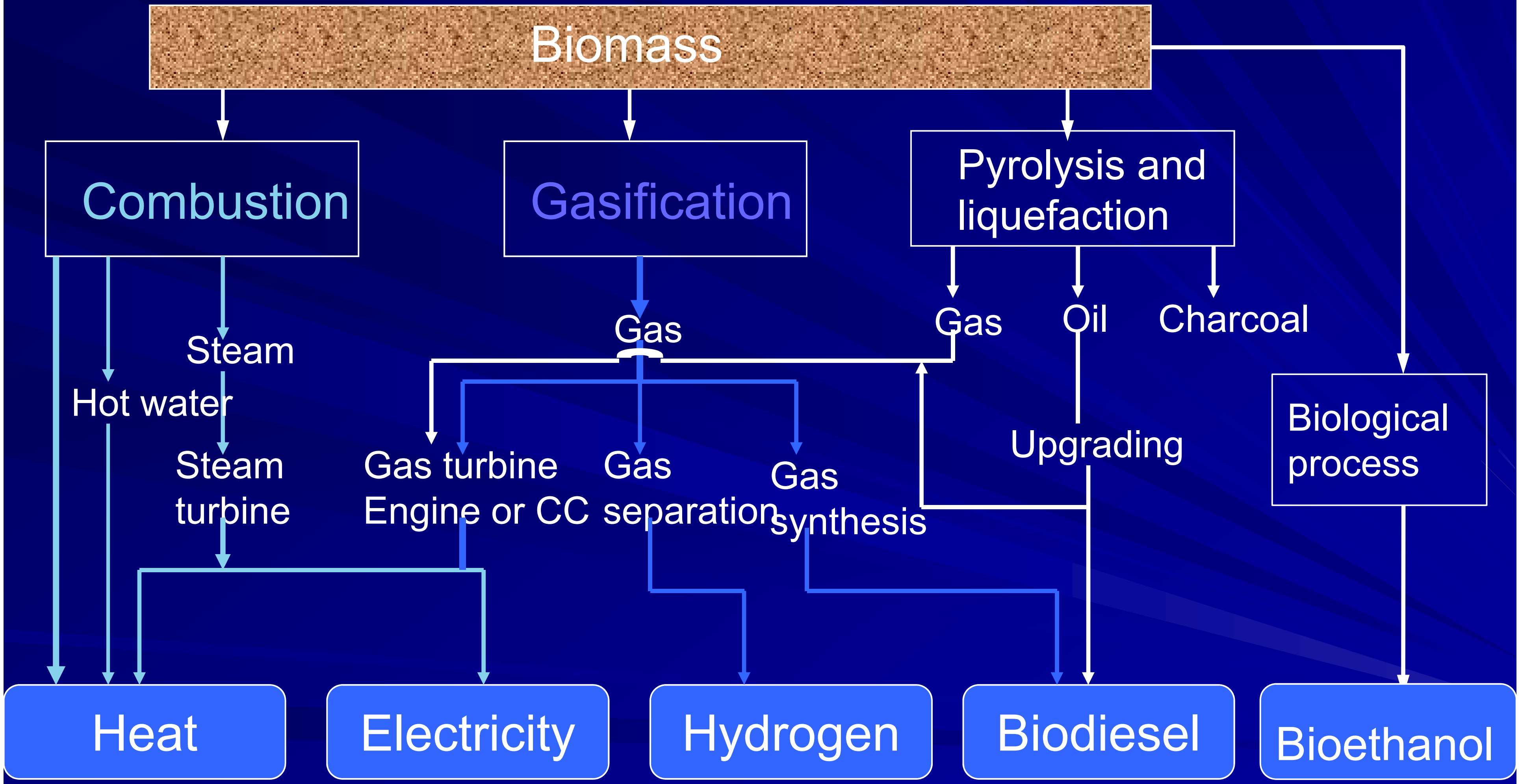
New Zealand also has strong potential to grow biomass crops in marginal lands

▲Jerusalem artichoke

◄ Jumbo (sorghum)

▼ Eucalyptus botryoides

Thermo-chemical and Biological conversion technologies



An extensive study on pathway analysis shows biomass gasification is a promising technology for CHP and liquid fuels#

Life cycle analysis of woody residues to consumer energy

Potential scale: up to 3.372 million ha of forest producing up to 600 PJ p.a. of primary energy.

Energy balance, GHG emissions, other environmental benefits, economics, technology status:

Summary

	Combustion Heat	Combustion CHP	Ethanol	Gasification Heat	Gasification CHP	Gasification Biodiesel
EROEI	7.5:1	4.9:1	3.5:1	5.6:1	4.0:1	3.9:1
Greenhouse gas reductions*	92%	94%	75%	90%	83%	83%
Cost ($/GJ)	$15.60	$27.60	$59.40	$31.20	$42.00	$34.50
Technology status	Mature	Mature	Developing	Developing	Developing	Developing

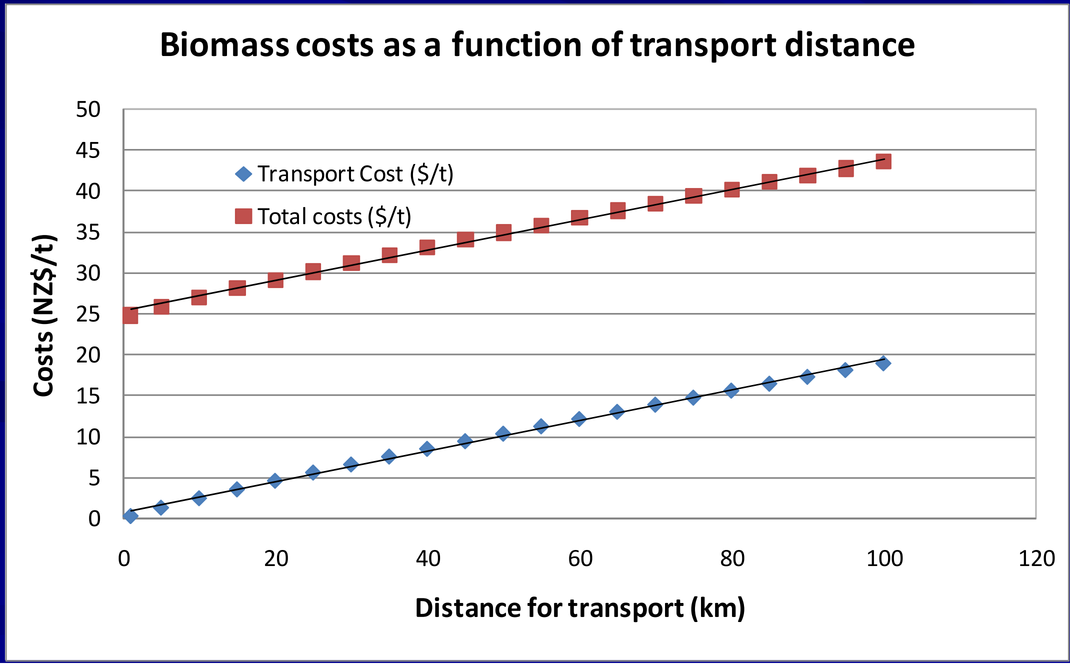
* Compared to heat from coal, electricity form the grid and fossil transport fuels

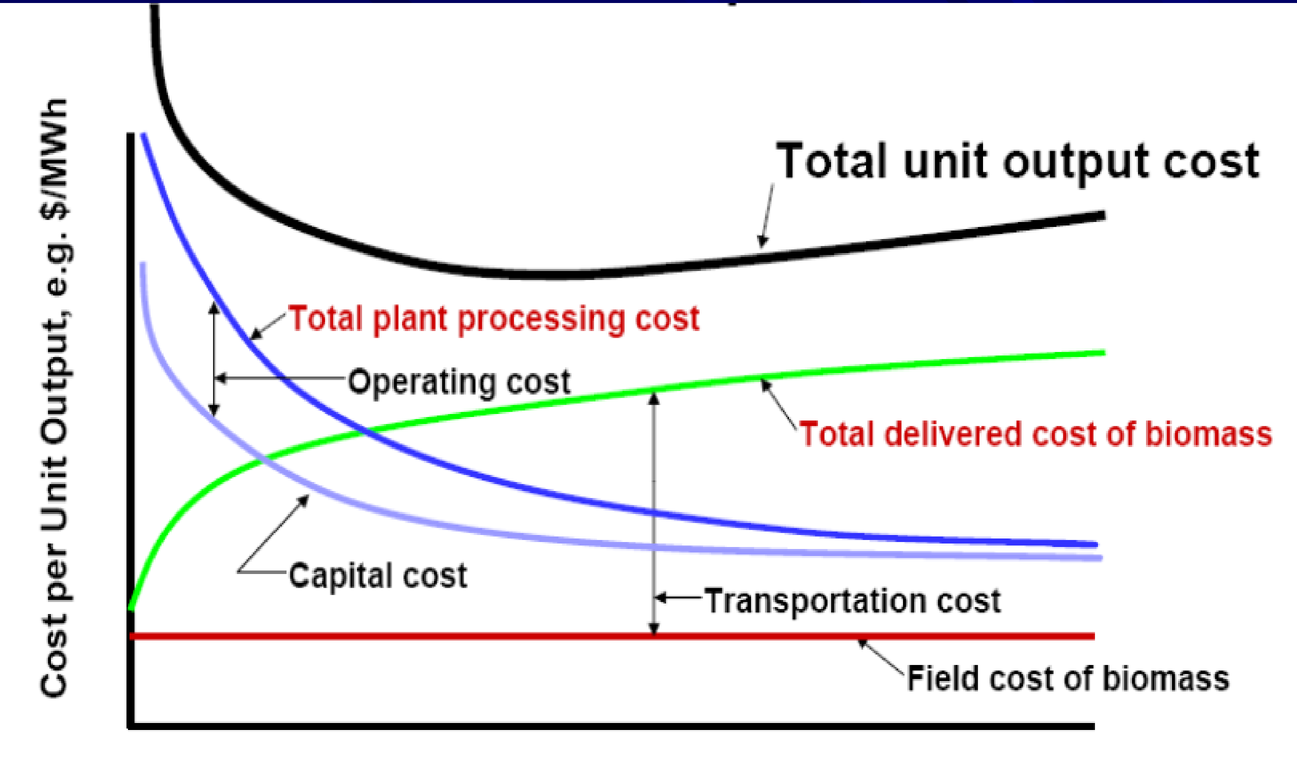
EROEI: Energy return on energy invested in the processing.

#: Hall, P. and Jack, M. 2009. Bioenergy Options for NZ: Pathway Analysis. A research report . Scion, Rotorua, NZ

Two Key Issues for Commercialisation of Bioenergy Technologies: costs and efficiency.

- From engineering points of view:
  - Large scale plants have high efficiency and low cost for unit output.
- However, biomass has low density and is widely distributed. Costs of biomass transportation and storage increase with the biomass quantity needed.





▲ Capital cost and operation cost for unit energy output are reduced with the plant scale. However, cost of biomass delivered to the plant increases with the plant scale.

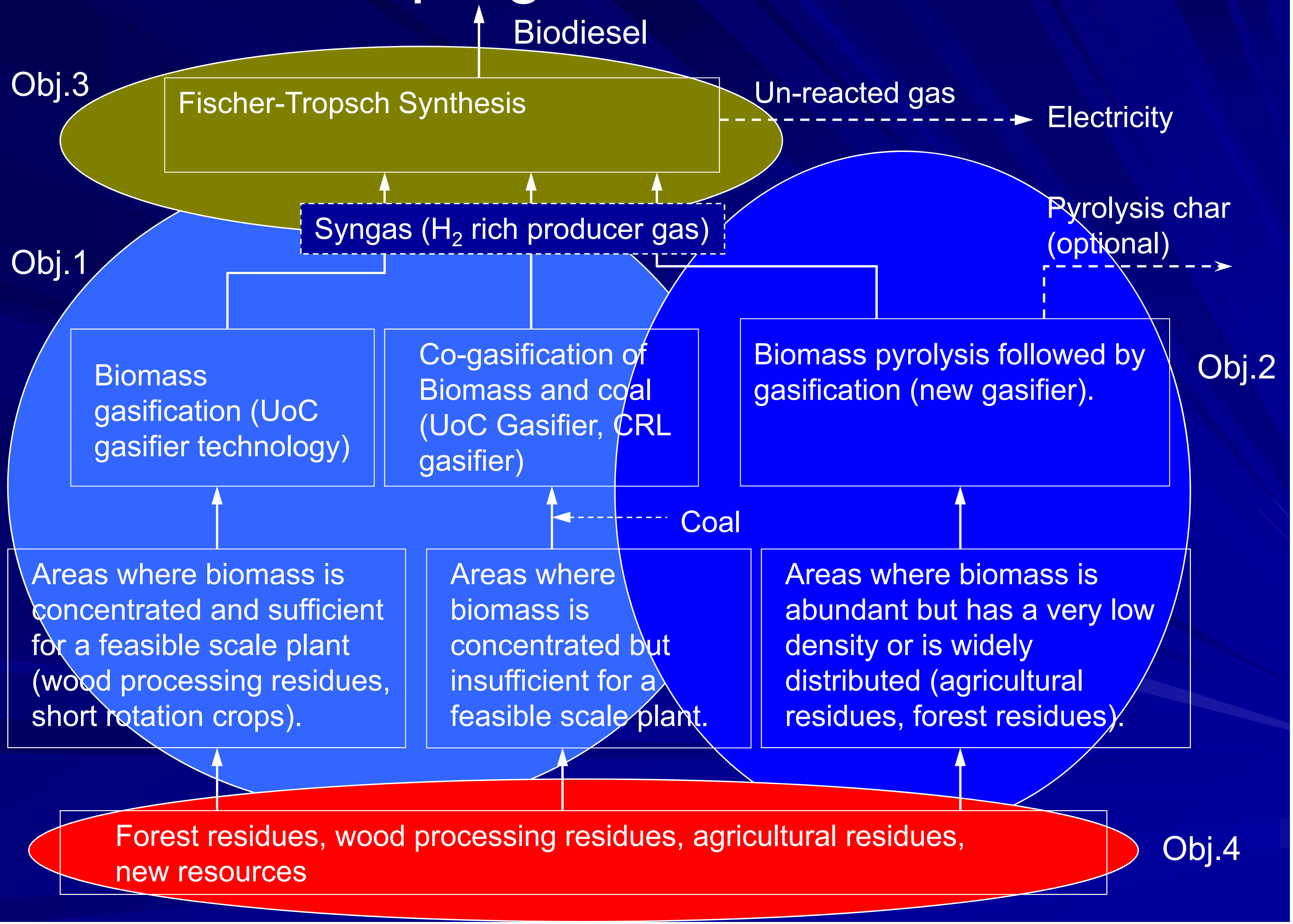
Sources:
1.K.R. Craig, NERL Report TP-430-21657 (1996).

Research at University of Canterbury: Biomass to Syngas and Liquid Fuels (BTSL) - Programme Objectives and Progresses

Aims of the BTSL programme

- To develop and adopt advanced technologies to produce clean hydrogen-rich syngas from biomass.
- To develop and adopt advanced technologies to produce 2nd generation liquid fuel using the hydrogen-rich syngas.
- To reduce costs of processing and pre-treatment of biomass to make production economically feasible.
- To establish new biomass resources and to evaluate unused resources of the biomass in NZ.
- To undertake feasibility studies and life cycle analysis for biomass energy and bioliquid fuel processing.

BTSL programme structure



New Programme on Biomass to Syngas and Liquid Fuel (BTSL)

- This research programme has been awarded with $NZ4.8 million for six years (2008-2014).
- Led by Shusheng Pang, the research team consists of
  - University of Canterbury.
  - Two NZ research collaborators.
  - Four companies from energy, forestry, wood processing and chemical industries.
  - Energy consultants in Advisory Board.
  - Collaboration with IEA Task 33, in particular with Vienna University of Technology.
- 6 PhD and 1 ME students.
- 2 new PhDs will join us in 2011.

Chronicle

UC UNIVERSITY OF CANTERBURY
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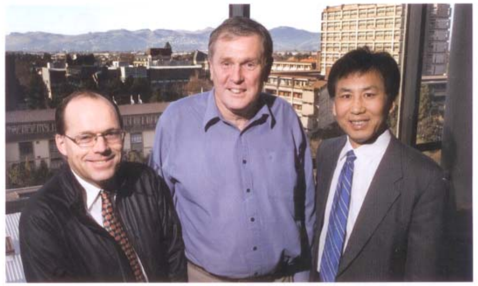
$10 million boost for UC research projects

Three projects led by University of Canterbury researchers have been awarded more than $10 million in funding in the Foundation for Research, Science and Technology's main 2008 investment round.

Each of the projects' industry partners have also contributed funding, taking the total to more than $11 million.

The successful lead researchers are Professor Phil Butler (Physics and Astronomy), Associate Professor Neville Watson (Electrical and Computer Engineering/Electric Power Engineering Centre) and Associate Professor Shusheng Pang (Chemical and Process Engineering). The funding was secured with the assistance of UC's Research and Consultancy staff.



(Left to right) Associate Professor Neville Watson (Electrical and Computer Engineering/Electric Power Engineering Centre), Professor Phil Butler (Physics and Astronomy), and Associate Professor Shusheng Pang (Chemical and Process Engineering) will collectively receive $10 million in funding from the Foundation for Research, Science and Technology.

Professor Butler's project aims to create a New Zealand industry supplying spectral X-ray detector systems to the international research and medical imaging markets. What will be known as the MARS (Medipix All Resolution System) imager will be manufactured and assembled by New Zealand industry for incorporation in the new generation of scanners manufactured by major global companies. The MARS imager will transform X-ray CT images from black and white to full colour.

"The transition from black and white to full colour in photographs, cinema, television and computer monitors has been much more dramatic and important than anyone predicted. We anticipate that true full-colour X-ray images will also be very dramatic and have positive impact on health care in New Zealand and the world," Professor Butler said.

It is estimated that the technology could eventually generate revenues of more than $400 million per annum.

Professor Pang's research team aims to develop technologies for production of hydrogen-rich syngas and second generation bio-liquid fuel. It will use New Zealand renewable energy resources of woody and agricultural biomass. It hopes to have a nine per cent share of the national diesel market by 2021.

"Our target is to reduce biomass transport costs and increase overall energy conversion efficiency thus making it feasible to build commercial biodiesel plants in NZ. The intermediate outcomes are to establish a new and international leading industry in New Zealand to produce high grade biodiesel from biomass and thus to contribute to securing national transport fuel supply," Professor Pang said.

To ensure biomass supply, new biomass resources of herbaceous species and short rotation crops will be developed.

Professor Watson's project seeks to address issues related to increasing demand for energy in New Zealand.

It will research the integration of renewable energy sources, such as small-scale wind power and solar power, with existing electricity networks, and its impact on what is known as power quality (PQ). This is the stability, reliability and resilience of electricity infrastructure.

Impacts can include blackouts, brownouts, as well as momentary interruptions and equipment malfunction or damage. Consequently, PQ problems impact the economy by directly affecting manufacturing, telecommunications and primary sector industries, such as dairy production.

Continued on page 2.

Inside your Chronicle

BTSL programme objectives

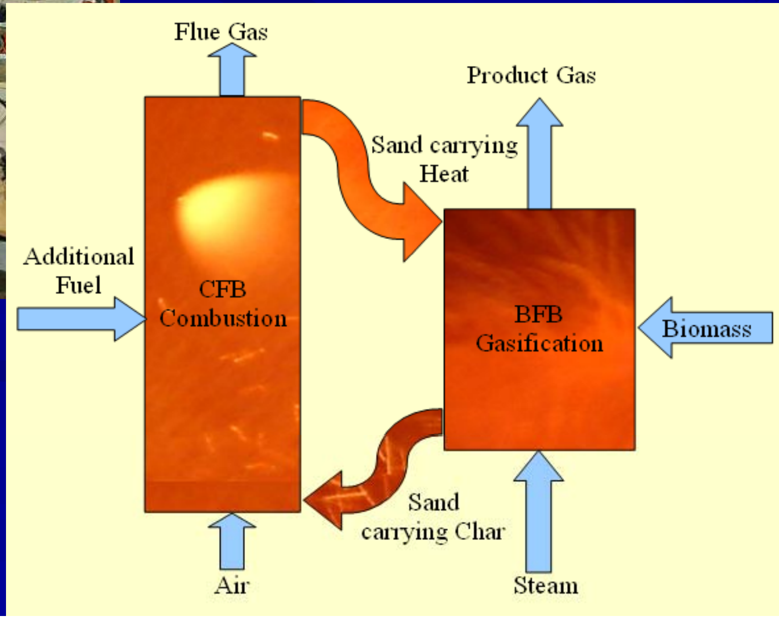
- Obj. 1: Optimisation of biomass gasification and co-gasification for clean and H_2 rich syngas.
- Obj. 2: Gasification of energy-densified biomass slurry (pyrolysis and gasification).
- Obj. 3: Fischer-Tropsch synthesis for biodiesel.
- Obj. 4: New biomass resources and feasibility studies for an integrated F-T plant.

Gasification of biomass for clean and hydrogen-rich syngas

- UoC has constructed and commissioned a 100 kW gasifier – Dual Fluidised Bed gasifier using steam as gasification agent.
- Has investigated impacts of operation conditions and various bed materials including Greywacke sand, Olivine sand, Calcite, Dolomite and Magnetite.
- Has tested biosolid wastes (to be presented by Dr. Saw).
- Has developed a new method for tar analysis (to be presented by Dr. Saw).
- Has been undertaken fundamental studies on the gasification process and co-gasification of coal-biomass blends (to be partially covered by Dr. Levi).
- Has been working on Fischer-Trosch synthesis of liquid fuel (to be presented by Chris Penniall).

The 100kW dual fluidized bed biomass gasifier in Chemical Engineering Department, University of Canterbury

- Challenges:
  - System is relatively complex thus suitable for scale above 20MW.
  - Value of the H_2 rich syngas should be fully explored.

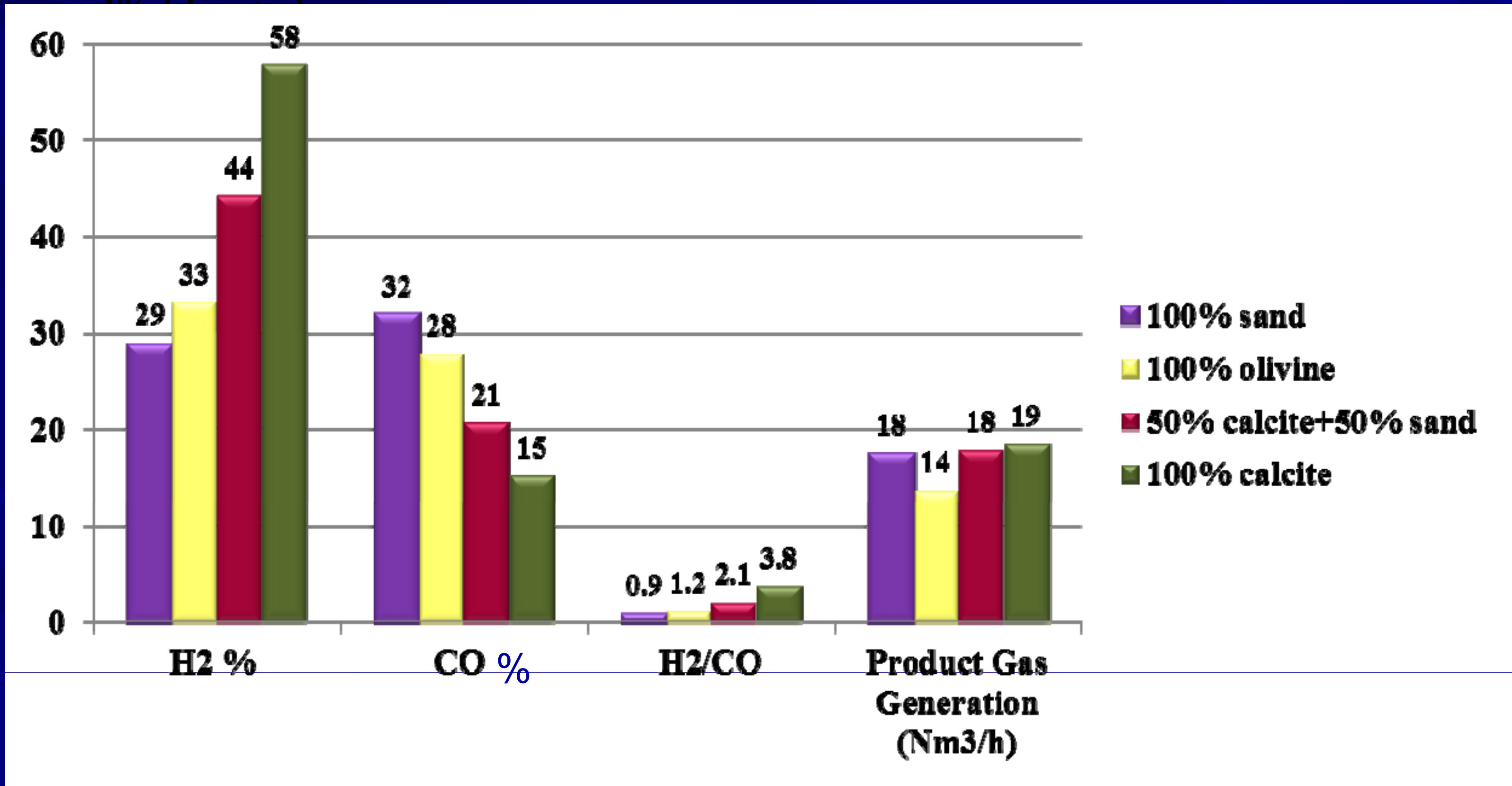


- Advantages of the technology:
  - High H_2 content in producer gas.
  - High heating values of the producer gas.
  - High efficiency.

Effects of catalytic bed materials
(J. Hongrapipat, W.L. Saw, I. Gilmour; S. Pang)

Wood Pellet Feed Rate = 15 kg/h; BFB Temperature = 720-750°C

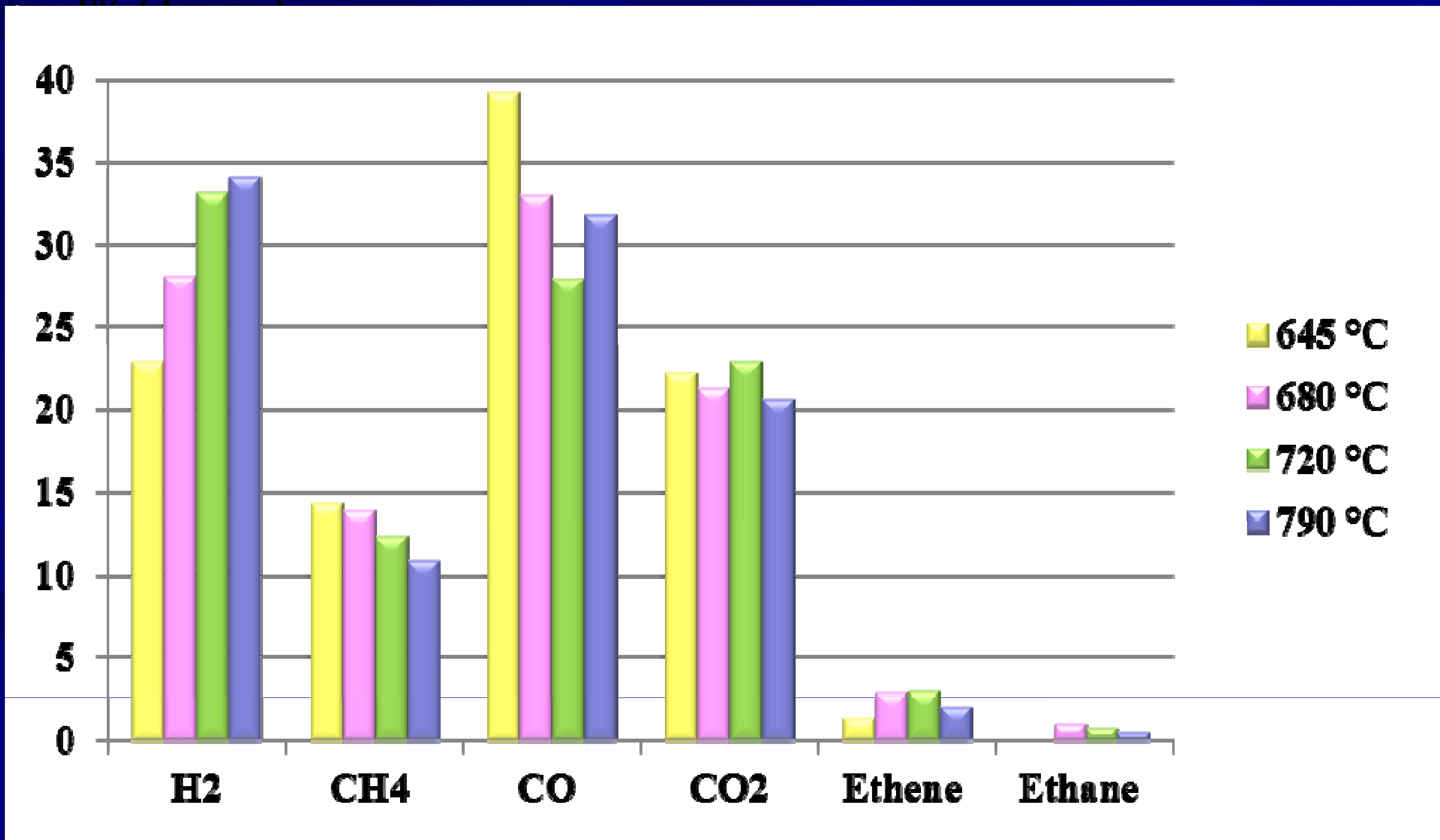
Steam/Biomass = 0.7-0.8; Catalytic Bed Materials = 18 kg



Effects of Gasification Conditions: gasification temperature
(J. Hongrapipat, W.L. Saw, I. Gilmour; S. Pang)

Wood Pellet Feed Rate = 15 kg/h; Steam/Biomass = 0.7

Catalytic Bed Materials = 18 kg of Olivine



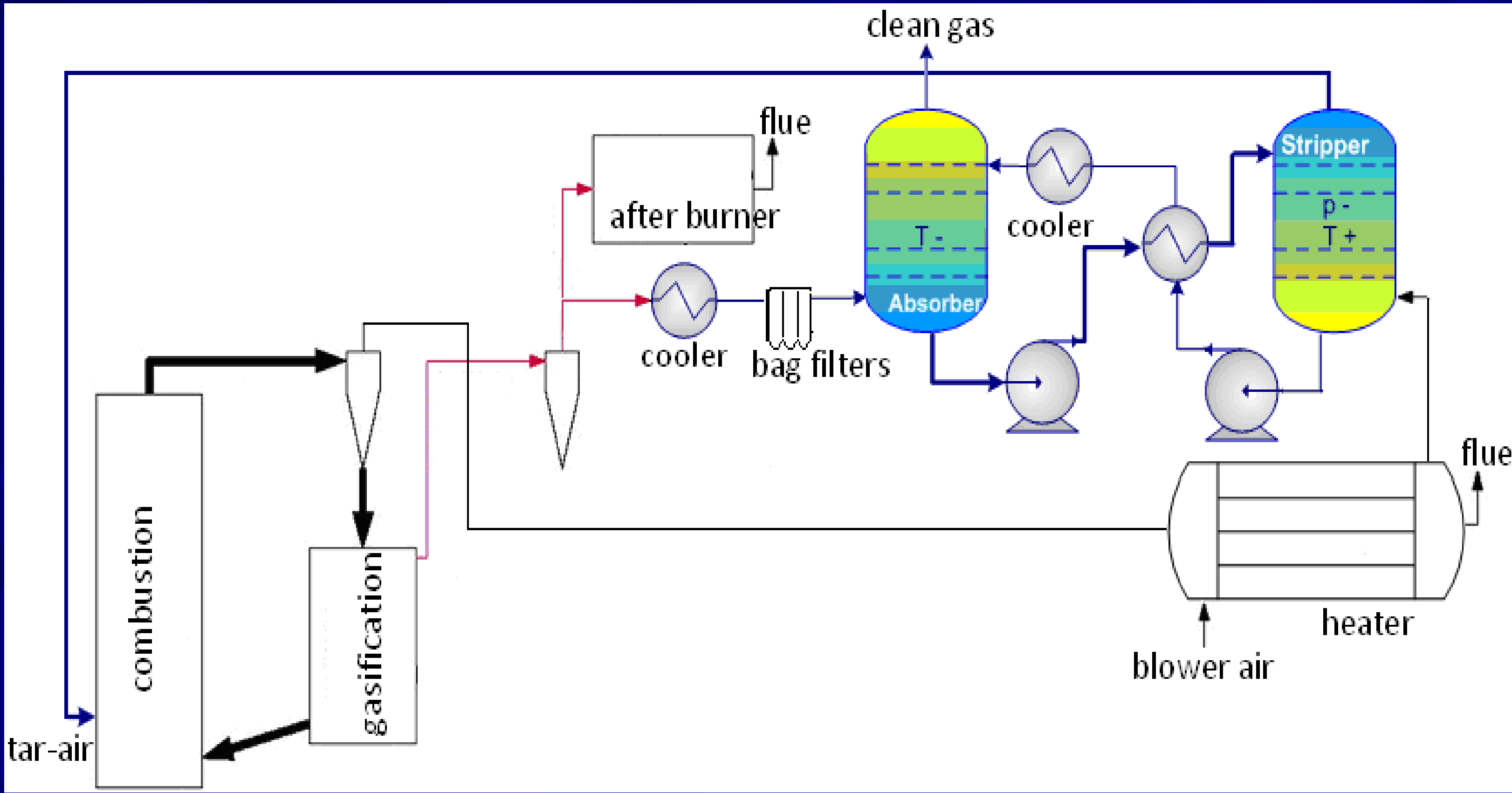
Biosolids (or Dried Sewage Sludge)

(W.L. Saw; I. Gilmour; S. Pang)

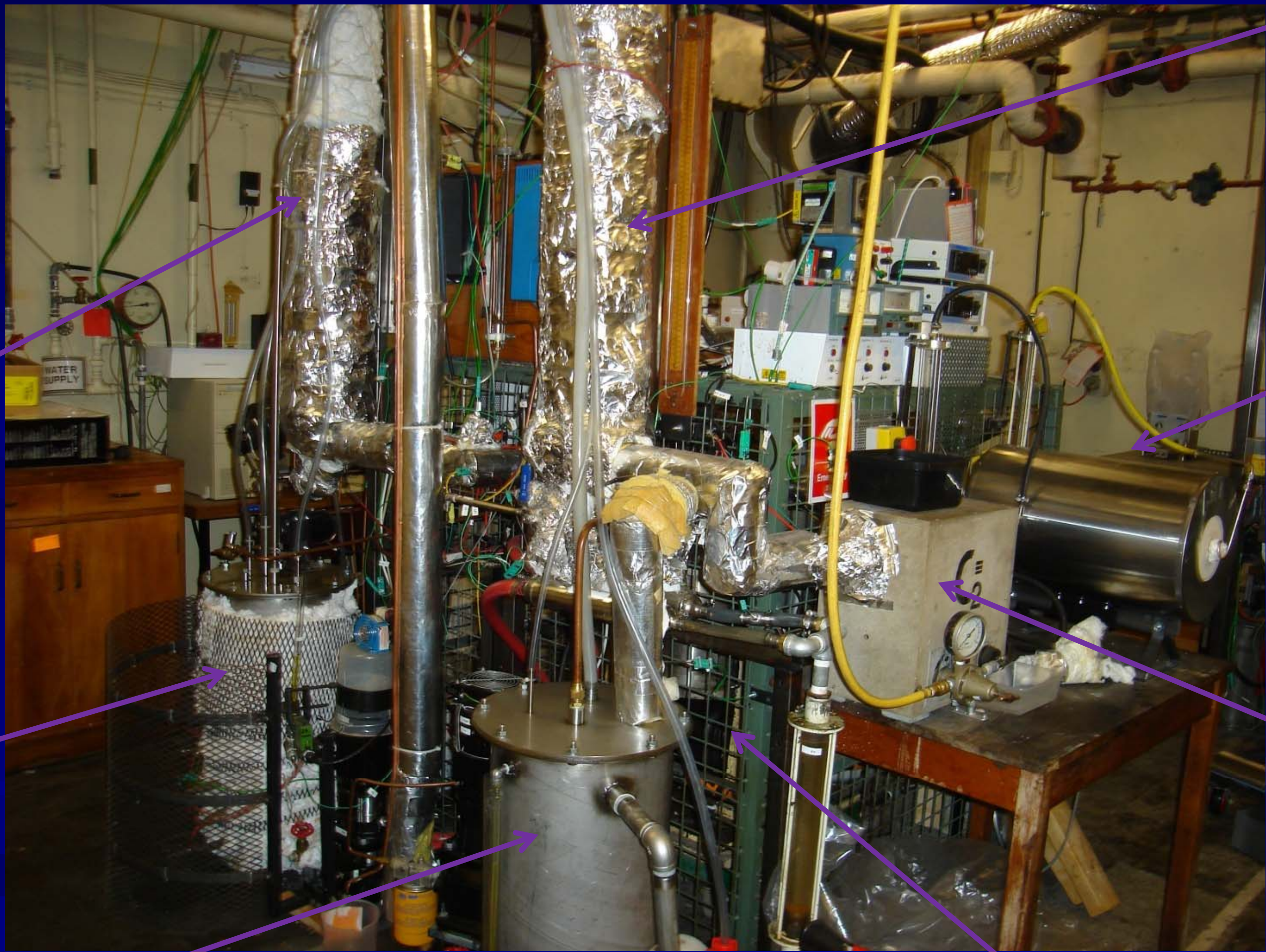
- The residue generated in the treatment of domestic and industrial waste-water.
- Large portion of biosolids end at landfill at present.
- Can be used as a potential renewable fuel.
- Approx. 6000 dry t/y of biosolids produced from Christchurch water treatment plant.
- Gasification tests show the producer gas consists of similar H_2 as biomass.

An Advanced Gas Cleaning System

- One unit for the removal of tar, H_2O and NH_3/HCl
- Whole regeneration of scrubbing liquid, i.e. biodiesel
- Tar recycle (into air) to the gasifier – energy recovery
- Gas quality is guaranteed.



An Advanced Gas Cleaning System



Stripper

Scrubber

Nitrogen pre-heater

Heated spent biodiesel

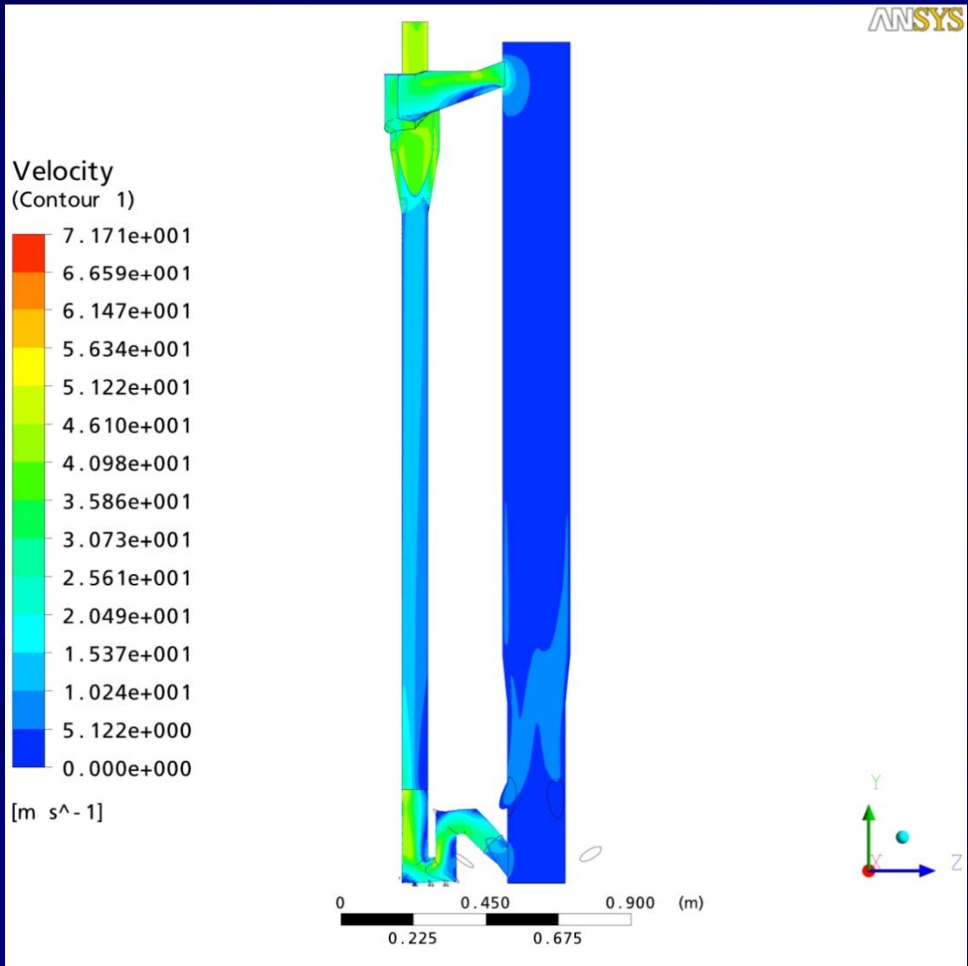
Air pre-heater

Cooled regenerated biodiesel

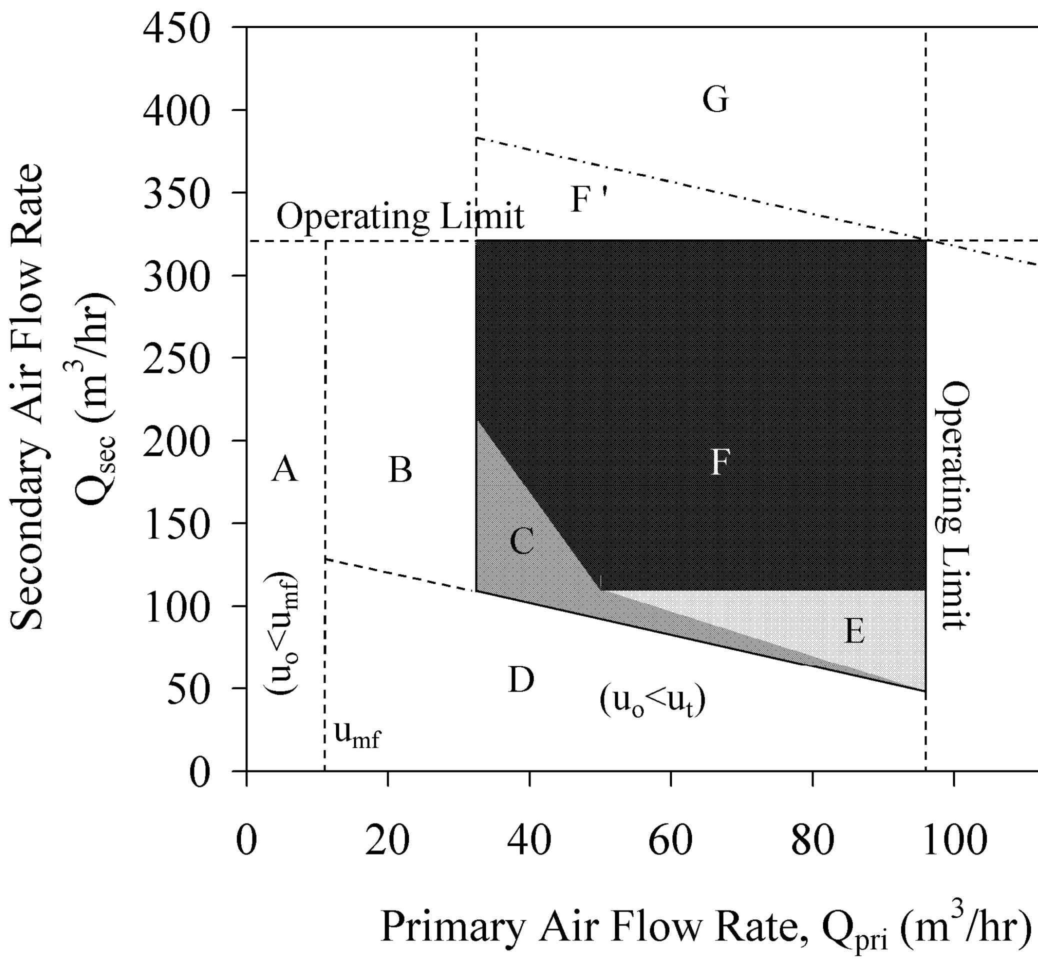
Tar vaporiser (autoclave)

Hydrodynamic studies for optimisation of plant design and operation

(M.T. Lim; J. Najdam; S. Pang)



Operational map for steady state operation of CFB riser.



A: No fluidization

B: Slugging

C: Loop-seal bypass

D: Bubbling fluidzation

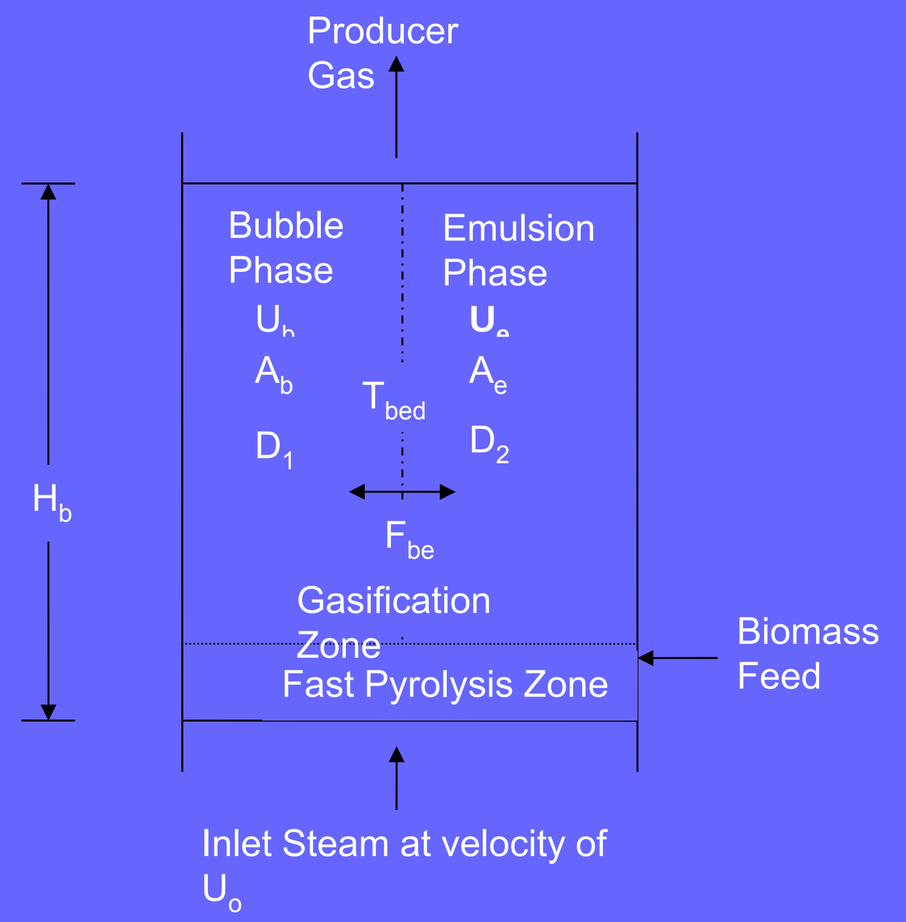
E: Elutriation regime

F: Fast fluidization regime

F’: Hypothetical fast fluidization regime

G: Loop seal overload

Two phase biomass steam-gasification model in a fluidised bed gasifier
(P. Gopalakrishnan and S. Pang)

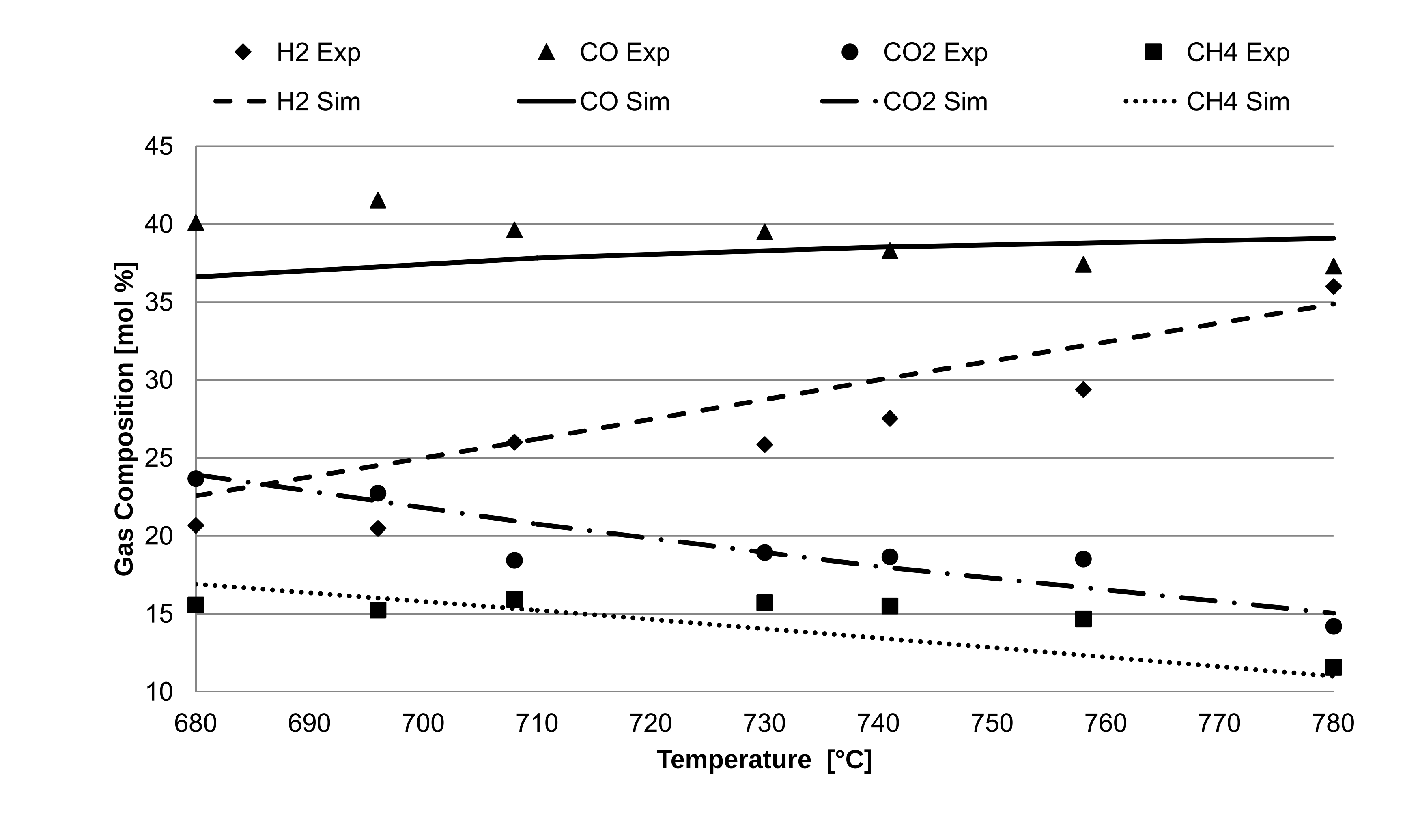


- Inter-phase heat and mass transfer of particles and gases between the regions.
- "Emulsion Region"- Mixing & distribution of solids & fluid . All reactions occurs.
- "Bubble Region" - only water gas reaction and methane reforming reaction occurs.

Gasification Reactions Considered in the Developed Model with Steam as Gasification Agent

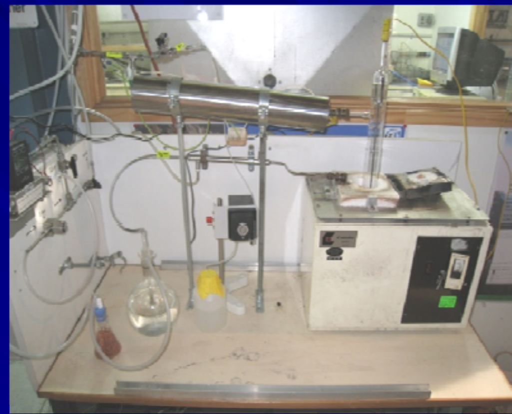
Reactions		Equilibrium temperature[K]	ΔG^o [J/mol]	ΔH^o [J/mol]
Steam Gasificati on	$C + H_2O \overset{K_1}{\Leftrightarrow} CO + H_2$	~948	-164.21	124978
Water gas - shift Reaction	$CO + H_2O \overset{K_2}{\Leftrightarrow} CO_2 + H_2$	~1098	-119.37	-63988
Methanation Reaction	$C + 2H_2 \overset{K_3}{\Leftrightarrow} CH_4$	~ 820	70.47	-32621
Bouduard Reaction	$C + CO_2 \overset{K_4}{\Leftrightarrow} 2CO$	~973	251.87	187667
	$C + 2H_2O \overset{K_5}{\Leftrightarrow} CO_2 + 2H_2$	~903	42.75	63065
Steam Methane Reforming Reaction	$CH_4 + H_2O \overset{K_6}{\Leftrightarrow} CO + 3H_2$	~ 893	-111.52	157224

Model validation and application for sensitivity analysis

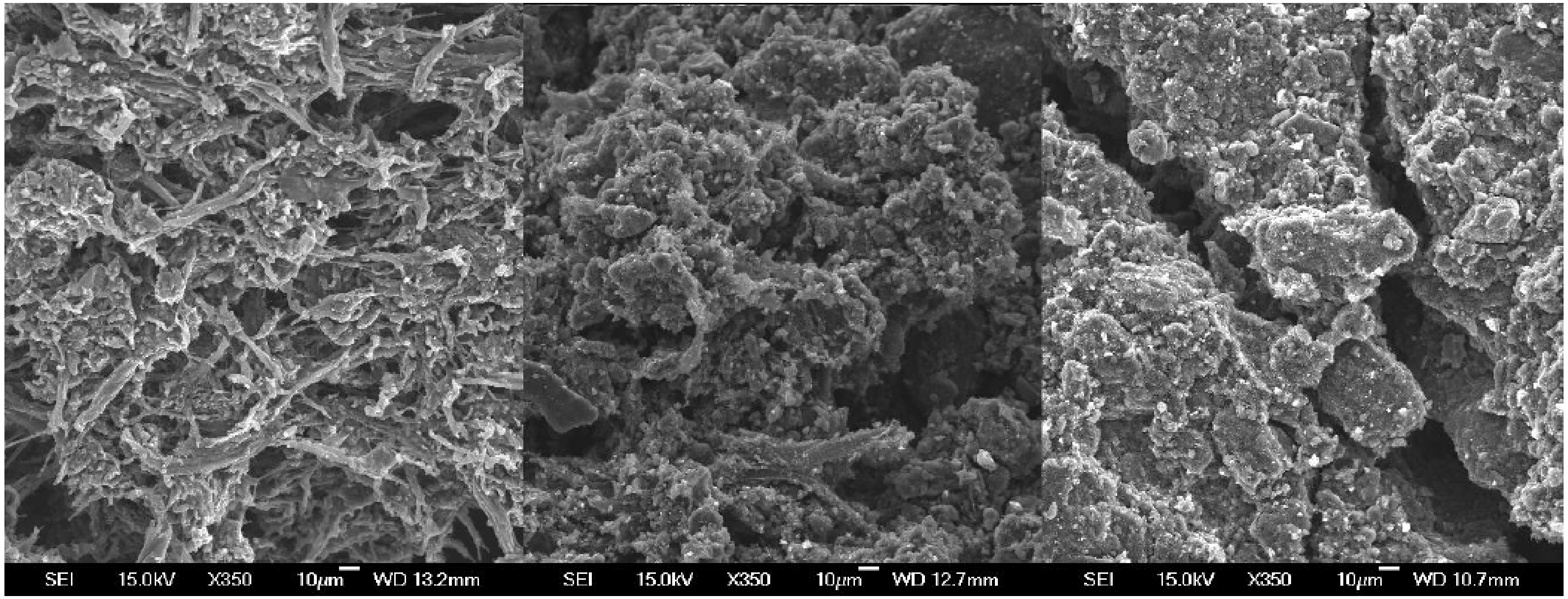


Studies on biomass-coal co-gasification
(Q. Xu, S. Zhang, T. Levi, S. Pang)

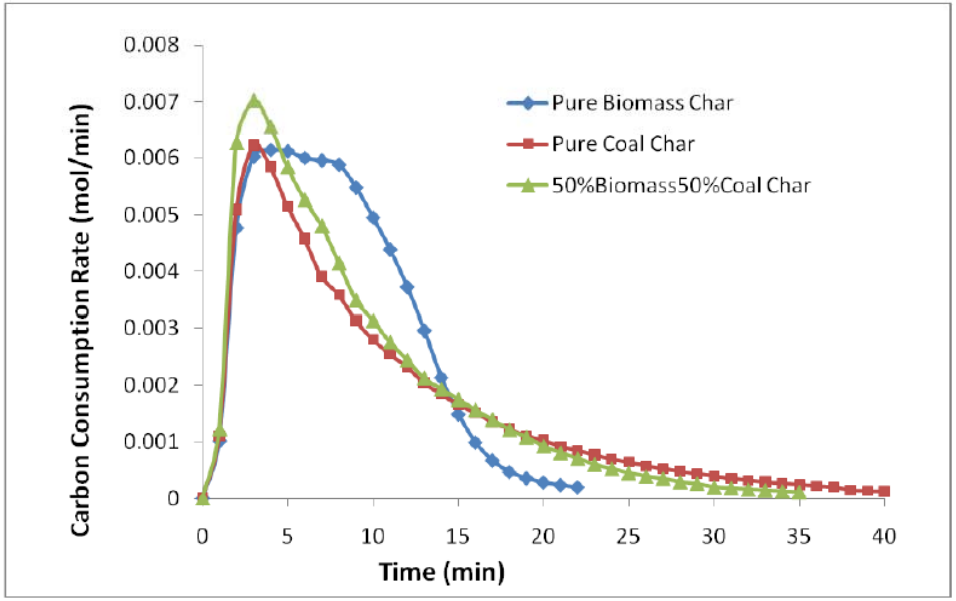




- Find a method to make coal-biomass pelletd.
- Determine reactivities of biomass, coal and their blends chars
- Identify differences between gasification of biomass, coal and their blend.
- Modeling of char gasification.



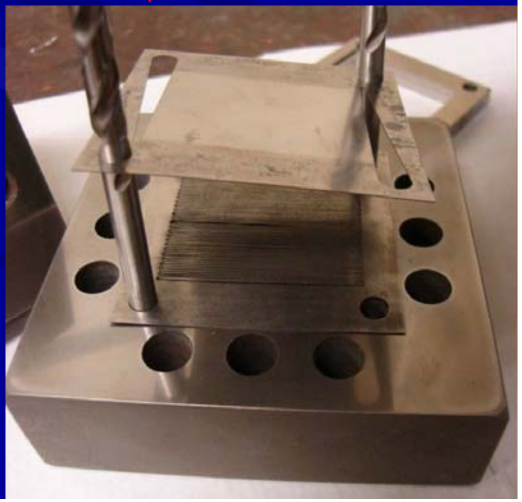
(a) (b)



References:
Xu, Q., Pang, S., Levi, T.
Cheml Engn Sci. 66 (2011)
Part 1: 2141-2148,
Part 2: 2232-2240.

Fischer-Tropsch (FT) synthesis of bio-diesel
(C. Penniall, C. Williamson, A. Marshall, S.Pang)

- Microchannel reactor
  - Heat and mass transfer rate is orders of magnitude greater than traditional reactors.
  - Suitable for catalytic processes.
  - Easy scalability and better economics at smaller scale than traditional technology.
- Catalyst
  - Cobalt on titania and alumina.
  - Challenge is to develop methods to incorporate catalyst with the reactor.



New Biomass Resources
(R. Renquist, Plant and Food Research Ltd.)

- Field trials have been conducted to grow perennial crops, summer annuals and winter annuals in various types of lands.
- Six strong contenders have been identified to have dry biomass yields of 12-26 t/ha/yr.
- *Eucalyptus globulus* has also been planted.

System Modelling and Feasibility Studies
(J. Li; N. Puladian; S. Pang)

- A system model structure has been proposed to include biomass collection or growing/harvesting, transportation, pre-processing, gasification, and liquid fuel synthesis.
- Data have been collected from this programme and from literature.
- LCA analysis for energy, carbon and exergy flows and efficiencies through the process.

Opportunities and challenges

- The advanced gasification technology has great potential in the near future for commercialisation with minimum risk.
  - It can produce high content of hydrogen and optimum ratio of hydrogen to CO (2) for liquid fuel synthesis.
  - It provides opportunities for production of multiple products such as liquid fuels as well as power and heat for integration with wood [processing plants.
  - The most promising application is the large scale sawmill or laminated veneer lumber.
- Capital cost and fuel cost versus scale needs to be optimised.

- Costs for conversion biomass to electricity and liquid fuels using the current technology are still higher than using fossil fuels, but it
  - Reduces carbon emissions.
  - Eliminates waste disposal costs.
  - Reduces dependence on fossil fuel.
  - Generates employment.
- However, with further R&D the costs will be reduced significantly in next 3-5 years. On the opposite, the use of fossil fuels will be more and more expensive!

Acknowledgements

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- The team members of BTSL programme:
  - Staff and postgraduate students at University of Canterbury
  - Research Collaborators: CRL Energy Ltd. and Plant and Food Research Ltd.
  - Industry partners and sponsors
  - Advisory Board members
- IEA Task 33 members (Biomass Thermal Gasification)