



# NSW & ACT POSTGRADUATE STUDENT ENERGY AWARDS 2006

## PROJECT SUMMARIES

University of Technology, Sydney  
from 5:00pm Tuesday 5 September 2006

Guest of Honour: George Maltabarow  
Managing Director – EnergyAustralia

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# INTRODUCTION

Welcome to the AIE Postgraduate Energy Awards for 2006. We would like to thank you for participating in what we are confident will be a very successful function for the students, the AIE and our sponsors.

The objective of this function is to give students the opportunity to present their postgraduate energy research projects to the energy professionals and interested public attending. The students' objective is to communicate their project and its relevance to energy through a poster display, a summary handout sheet (bound into this volume) and the student's personal explanations. These projects range from ones which have just commenced where the problem and scope is still being identified, to projects where the thesis may already be complete.

As energy professionals, where appropriate, please provide constructive advice and assistance to them, based on your experience. We are confident you will also benefit from learning more about the leading edge research being conducted outside your area of expertise and maybe broaden your approach to Australia's energy debate.

We would particularly like to take this opportunity to thank our sponsors whose generosity has made this function possible. The sponsors are listed below, with their web sites for you to get further information on their interests and activities. Please check them out and give them your business.

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We take this opportunity to thank the students for their efforts in preparing and presenting the project posters. We congratulate the graduates for the high standard of their displays and presentations and thank them for their efforts on our behalf. In addition to the Awards, the AIE is pleased to host each of the participating students to the dinner later this evening, as well as providing them with free introductory student membership of the AIE.

Dr Tony Vassallo  
Chair  
AIE Sydney Branch  
On behalf of AIE Sydney, Newcastle & Canberra Branches

## THE AWARDS

For the purpose of the Awards, the 18 projects have been divided into three categories:

- 1 – Energy in Society
- 2 – Innovation in Energy Science & Engineering
- 3 – Energy – Achieving More With Less

For each category, the Judges will select a First Prize, Second Prize and Encouragement Award. Students can only win one award. There will also be an award for the Best University Contribution, based on the number and quality of their student applications.

First Prizewinners will receive a cheque for \$1000, a plaque, and a travel bursary to attend the AIE National Postgraduate Student Energy Awards in Melbourne in November 2006.

Second Prizewinners will receive a cheque for \$500 and a plaque. The Encouragement Award in each category will be a cent-a-meter, from Wireless Monitors Australia.

All student entrants will receive 1 years student membership of the Australian Institute of Energy.

### **The Judging Panel:**

Michael Kachka	NSW Department of Planning
Glen Currie	CSIRO Energy Technology
Richard Hunwick	Hunwick Consultants
Ron Ripple	Macquarie University
Neil Gordon	EnergyAustralia
Ben Hamilton	Country Energy
David Hemming	NSW Dept of Energy, Utilities & Sustainability
Rob Helstroom	NSW Department of Planning
Bruce Lipscombe	Confac
Sarah Ryan	Agility
Allen Lowe	Consultant
Chris Sorrell	University of NSW

## SUMMARY OF STUDENT PROJECTS AND CATEGORIES

No.	Surname	1st Name	Year	Inst	Project	Category
PGA0601	Kordjamshidi	Marie	3rd yr	NSW	Development a new framework for house rating scheme (HRS)	Energy in Society
PGA0602	Ramasamy	Shanmugan athan	1 of 3	Newcastle	Microwave non-destructive characterisation & imaging of wood	Achieving More With Less
PGA0604	Wood	Richard	2nd yr	Sydney	Structural decomposition analysis of Australian energy consumption	Achieving More With Less
PGA0606	Shen	Yansong	3rd yr	NSW	Modelling of coal blends combustion: a cost-effective way of providing in-depth information for fossil fuel utilization	Achieving More With Less
PGA0607	Gibbes	Greg	1 of 2	UTS	Numerical modelling of the charge process in a prtotype free-piston engine	Innovation in Energy Science & Engineering
PGA0608	Badat	Yusuf	2nd yr	Newcastle	An investigation into the behaviour of SiO <sub>2</sub> -bearing mineral matter of coking coals during coking and in blast furnace	Innovation in Energy Science & Engineering
PGA0610	Sharma	Kunal	2nd yr	Newcastle	Exploring the use of ilmenite as a potential oxygen carrier in a chemical-looping combustion process (CLC)	Innovation in Energy Science & Engineering
PGA0611	Khare	Sameer	3rd yr	Newcastle	Heat transfer in Oxy-fuel coal combustors	Innovation in Energy Science & Engineering
PGA0612	Stevanov	Chris	2nd yr	Newcastle	Effect of pyrolysis conditions on structural transformations, and their combined effect on biomass combustion reactivity	Innovation in Energy Science & Engineering
PGA0613	Rathnam	Renu	1 of 3	Newcastle	Differences in reactivity of puvierised coal in air (O <sub>2</sub> /N <sub>2</sub> ) and oxy-fuel (O <sub>2</sub> /CO <sub>2</sub> ) environments	Innovation in Energy Science & Engineering
PGA0614	Wood	Susie	2nd yr	Sydney	Oxidation of methane in mine ventilation air using porous burners	Achieving More With Less
PGA0616	Vaiyavuth	Ronnakorn	Final yr	UTS	The relationship between electricity and gas industry in Australia	Energy in Society
PGA0617	Uddin	Noim	2 of 3	Macquarie	A sustainable energy future in Bhutan: trends and strategies	Energy in Society
PGA0619	Zhao	Zheng (Jerry)	2nd yr	Wollongong	Mesoporous carbon nanocomposite for electrochemical power sources	Innovation in Energy Science & Engineering
PGA0620	Turville	Stephen	Final yr	NSW	Fuelling Australia's transport future	Energy in Society
PGA0621	Beck	Jessica	4th yr	Sydney	Systems approach to evaluating renewable energy projects	Energy in Society
PGA0622	Kempener	Ruud	2nd yr	Sydney	The effect of social factors on the evolution of energy systems	Energy in Society
PGA0623	Florin	Nicholas	2 of 3	Sydney	Production of H <sub>2</sub> from biomass coupled with CO <sub>2</sub> capture	Achieving More With Less

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## DEVELOPMENT A NEW FRAMEWORK FOR HOUSE RATING SCHEME (HRS)

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### Project Summary

There has long been concern that rating building thermal performance on the basis of predicted normalized energy requirement ( $\text{MJ/M}^2$ ) is inappropriate to achieve overall energy efficiency of houses. This study proposes a new method for House Rating Schemes, in which the efficiency of a house design will be evaluated with reference to its thermal performance in free running and conditioned operation modes. A thermal comfort indicator is developed to evaluate free running performance. By attributing more value to free running houses, it is assumed that policy objectives to reduce energy demand for space heating and cooling in the residential building sector are more likely to be achieved.

Simulation is used to compare the predicted performances of houses in free running and conditioned operation modes for moderate climates of Sydney and Canberra. Parametric sensitivity analysis and multivariate regression analysis have been employed and point to the following results.

The reliability of a free running rating scheme, in terms of addressing energy efficient aspects compared to the current energy base rating is demonstrated. The research illustrates significant differences between efficient design for conditioned houses and free running houses. The findings strongly suggest the necessity of developing a new regulatory framework to reduce energy demand in the housing sector. Utilizing these findings an aggregation of two rating system in the form of a new house rating framework is developed. The research approach can deliver significant benefits in terms of energy demand reduction and sustainability, if it is employed as a basis for House Ratings Schemes.

## MICROWAVE NON – DESTRUCTIVE CHARACTERIZATION & IMAGING OF WOOD

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### Project Summary

#### Background:

The characterization of wood properties is critical for the understanding its material behaviour and performance under operating conditions. The imaging of wood structure using microwave techniques is based on the determination of its dielectric properties. For the correct interpretation of microwave imaging it is necessary to know the response of the material to the electrical and magnetic fields, and also to understand the mechanism of the interaction between the sample and the probe. The industrial applications were originally oriented primarily toward the improvement of drying and glueing technology. Today, the industrial applications of the microwave imaging techniques are related to the detection of internal defects such as knots, spiral grain, and structural discontinuities of logs, lumber and wood-based composites. The microwave imaging technique has several advantages such as a non-contact operating system and relatively small size of antennas (determined by the wavelength at microwave frequencies), and its fine resolution of measurements which increases the ability of this technique to detect very fine defects.

#### Aims & Significance:

The aim of this project is to obtain a high resolution image which will help to monitor the wood cell structure at different stages during the combustion process. This will be achieved through different Microwave Non-Destructive Evaluation Technique [Transmission, Reflection & Resonance]. Signal analysis is relatively simple and is related to the measurement of amplitude, phase and the polarization of the waves. These parameters are used for image reconstruction of wood structure. The imaging of wood structure can be accomplished by scanning in the proximity of the sample with a resolution given by the antenna aperture size. The images can be obtained in the far field or in the near field. In the far field, the smallest detectable defect size is determined by the ratio  $d/\lambda > 1$ , where  $d$  is the length of the defect in the plane normal to the microwave vector and  $\lambda$  is the wavelength. The near field approach will improve the resolution of imaging as well as we can obtain the resolution with the lower frequency itself which doesn't depend on the wavelength.

#### Methodology:

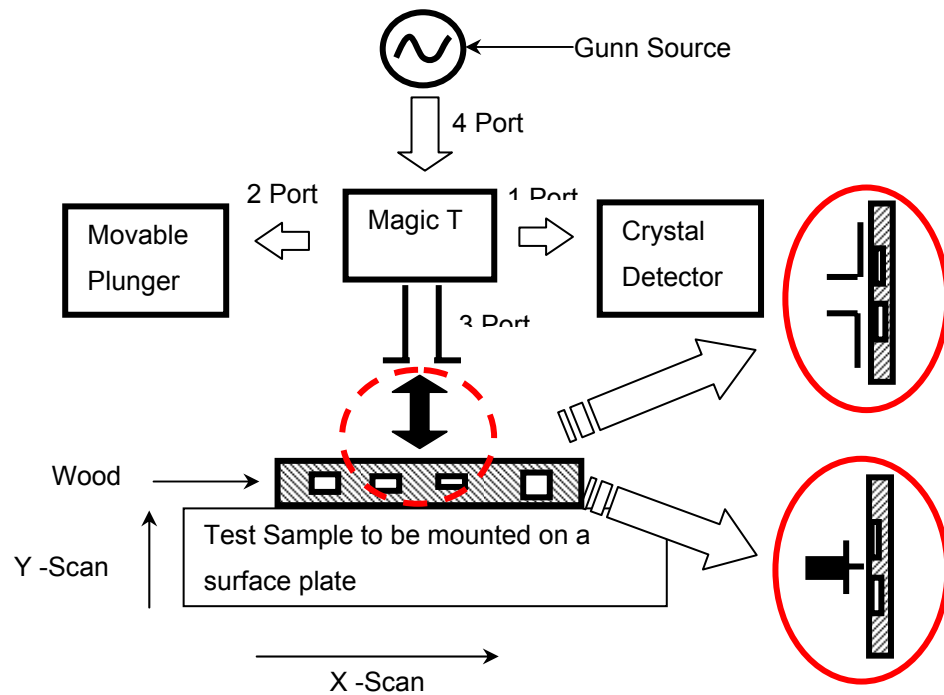
This project will be an experimental study aimed at imaging of the wood structure for detection of internal defects such as knots, spiral grain, slope of grain. Initial experiments will be carried out using the vector network analyser to finalize the parameters such as frequency, power, transmitting probe and the detection sensitivity. Based on the parameters a customized microwave experimental setup with a XY stage scanner will be designed and developed in the laboratory for imaging the wood structure.

#### Expected Outcomes:

The proposed work will lead us to monitor the wood cell structure at different stages during the combustion process in order to know the porosity level and the structural changes through microwave

imaging. The physical, mechanical & chemical properties of wood will be studied and which will help us to produce composite wood for advanced product design.

### Experimental Set-Up:



# STRUCTURAL DECOMPOSITION ANALYSIS OF AUSTRALIAN ENERGY CONSUMPTION

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## Project Summary

The problem of decoupling economic growth from energy consumption, and associated negative impacts, is perhaps one of the central challenges we face. The demonstration of this challenge, however, is made somewhat indiscernible by the complex systems of production embedded in our economic structure which link our levels of growth to our energy footprint. We are often able to achieve improvements in efficiency in one area, which are subsequently nullified by other effects. Or whilst progress may be made in curtailing energy-intensive consumption, erstwhile changes within the production chain may only serve to shift the impact. Thus, from a national perspective, policy formed from a whole of production/consumption perspective will likely be most effective.

Over the last 30 years, significant changes have occurred in the Australian economy and in this study, these changes have been analysed using a comparative-static technique of input-output analysis known as structural decomposition analysis. This enables the growth-consumption-production-impact linkages to be explicitly modelled from a holistic top-down perspective. Decomposition of the linkages can be performed at a high level of detail, both from the perspective of the types of linkages, and the number of industrial linkages. This study advances the methodology of indexing techniques; scope; and decomposition level, as outlined below.

Utilising 15 time periods over the 30 years, the types of linkages investigated include changes in: fuel mix, industrial efficiency, inter-industry structure, type of final demand, cause of final demand, population affluence, population size, and type and level of exports. Changes in fuel mix reflect the changes in the types of fuels used in Australia over the period. Industrial efficiency reflects the change in direct energy requirements of Australian industry. Inter-industry structure reflects the changes in economic linkages and requirements of the Australian economy to produce the type of final demand – which corresponds to the changing levels of demand of products and services in Australia. Cause of final demand reflects the changing amounts of private, government and capital expenditure. Population affluence and population size are self explanatory and modelled explicitly, and due to the important and variant nature of exports in Australia, both the mix and level are also modelled explicitly.

Principle results show that historically, significant competing forces at both the whole of economy and industrial scale have been mitigating potential improvements. Key sectors and structural influences are identified that have historically shown the greatest potential for change, and would likely have the greatest net impact.

In terms of greenhouse emissions, at a macro-level, changes in fuel mix, energy efficiency, final demand mix, final demand destination and export mix were found to historically have a negative (decreasing) impact on emissions. The change in energy efficiency was the strongest component of this group, and showed a high variability that could be exploited through directed policy. In contrast, changes in structural interrelationships, affluence and export level strongly increased emissions.

At the disaggregated level, the importance of the electricity supply, construction, transport and - less intuitively – the service industries was confirmed, but no industry showed a constant positive or negative impact over the full time series. A further important result was that there appeared to be a high level of substitution between energy and structural inputs, with diminished total effects. This suggests that the real gains in energy efficiency would not be as great as an energy intensity analysis would show, and that the consideration of impacts embodied in production was needed to capture all effects.

# MODELLING OF COAL BLENDS COMBUSTION: A COST-EFFECTIVE WAY OF PROVIDING IN-DEPTH INFORMATION FOR FOSSIL FUEL UTILIZATION

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## Project Summary

**Objectives:** Coal is a primary energy source for electricity generation and for metallurgy industry worldwide. It is especially a case for Australian power generation and metallurgy industries. Combustion of coal blends is widely practised coal-fired power plants and in blast furnace ironmaking. In coal-fired boiler in power stations, coal blending is widely used to improve coal flexibility, improve combustion behaviors, mitigate operation problems (e.g. ash deposition), and reduce pollutants emissions. Coal combustion is rarely completed in power station boilers. A small proportion of the coal is emitted from the boiler as partially burned char (unburned carbon). This incomplete burnout of char not only restricts the overall combustion efficiency of the station but also limits the potential markets for the resultant fly ash (used in construction industry). In addition, high levels of unburnt carbon in the fly ash can also seriously impair the operation of the electrostatic precipitators. In blast furnace ironmaking, similar to boilers, pulverized coal injection through tuyeres into furnace raceway is used to lower operating costs and to maintain furnace operation stability. Coal blends enables better control of coal quality and allows selection of a blend to optimise combustion. While as the levels of coal rate increases, the burnout of coal within the tuyere and raceway becomes increasingly important, as unburnt char, with ash, impacts on the permeability of the raceway boundary and ultimately on the furnace stability. Therefore, it is desirable to be able to characterize the burnout behaviors of the coal blends prior to full scale trials in both industries.

**Methodology:** CFD modelling provides an accurate and cost effective tool for optimizing operation and lance/burner design. In particular, it can provide insight into the combustion characteristics of unfamiliar coals and blends. While the combustion performance of a coal blends is more complex than that of a single coal because it is not only dependent on the combustion performance of the component coals but also on the physical/chemical interactions between coal particles. In the present study, a three dimensional model for coal blends combustion is developed to simulate the flow pattern and combustion performance of binary coal blends. In this work, in a blend, two different types of coals, with varying physical and chemical properties, are considered and tracked separately, and two component coals undergo individual reactions using individual reaction kinetics, and interact through local competition for oxygen supply. The model is then validated against the experimental measurements obtained from a pilot-scale combustion rig in terms of coal burnout. Therefore, this model offers a cost-effective tool to predict the combustion behaviour of coal blends, especially blends of unfamiliar coals before full scale trial, and to provide in-depth information and comprehensive understanding on hybrid effects from various coals on temperature profiles, burnout rate, gas species, pollutants emission etc. for power station and ironmaking. It is also helpful for coal selection for coal suppliers.

**Keyword:** coal blends, CFD, coal combustion, power generation, blast furnace

# NUMERICAL MODELLING OF THE CHARGE PROCESS IN A PROTOTYPE FREE-PISTON ENGINE

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## Project Summary

This study was commissioned by Pempek Systems in the continuing development of their free-piston engine project.

**Engine overview:** A free-piston engine is one where the piston is not mechanically driven, but transmits force by some other method, most commonly by hydraulic force or magnetic force. The Pempek engine has an integral linear generator and is designed to efficiently convert the chemical energy of fuel to electrical power. This implementation of the internal combustion engine has a number of benefits;

- infinitely variable compression ratio
- few sliding surfaces (no shafts, cranks etc)
- minimal side load on the piston
- compact size

The engine is ideally suited to providing the power for electric vehicle technology thanks to its compact dimensions, robust and simple design and multi-fuel ability.

**Specifically:** The engine configuration is two symmetrically opposed combustion chambers and a single moving element which traverses between them. The gas transfer in the cylinders occurs once every cycle (2 strokes). Exhaust is achieved via poppet valves in the cylinder head and intake is via passive poppet valves in the piston crown – a form of uni-flow scavenging. To drive the scavenging process, the intake air is pressurised by an integral compressor piston. The performance of the gas exchange (scavenging) is an important design problem since the mass of fresh air trapped in the cylinder largely determines the maximum power of the engine. High speed gas dynamics often exhibit complex interactions, and the system is further complicated by the dynamic behaviour of the passive intake valves (PIV).

**The Project:** Due to the difficulties of experimental investigation of the gas behaviour in-cylinder, a numerical tool is sought that can describe the physics of the charge process with a view to optimise the engine design and performance.

Computational Fluid Dynamics (CFD) applies the governing equations of fluid flow to a discretised spatial grid that represents the flow domain. It is the keystone tool in this investigation. However it requires careful application to the problem. Highly unsteady problems (such as this) pose a particular challenge for CFD. An important part of this project is verifying results. This is done using available experimental data, published benchmarks, exact analytical solutions and internal consistency.

Initially, the whole problem will be analysed in two dimensions. The flow domain extends from the closed compressor volume to the end of the exhaust pipe. Factors expected to influence the charge process include PIV design, intake duct shape, compressor dimensions, mover motion, exhaust valve timing and trajectory, exhaust pipe dimensions. A parametric investigation will be used to find trends and behaviour of the charge process while varying the above parameters.

A three-dimensional investigation will follow. It will test certain simplifying assumptions of the 2-D geometry, and allow a detailed “look” at the in-cylinder flow during scavenging and the compression stroke. Again, proposed design changes can be tested for the likely influence on charging.

# AN INVESTIGATION INTO THE BEHAVIOUR OF SiO<sub>2</sub> – BEARING MINERAL MATTER OF COKING COALS DURING COKING AND IN BLAST FURNACE

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## Project Summary

The roles of coke in the iron-making blast furnace are numerous; the most important being that it supports the weight of the burden materials and provides a permeable medium for the upward flow of gases and downward flow of liquid iron and slag at the bottom of the furnace. In order to achieve this, it must be strong, have a relatively large size and maintain a uniform size distribution during its journey through the blast furnace.

Reactions with mineral matter contained in the coke with the coke carbon cause the coke to degrade. The rate at which mass is lost as a result of these reactions is influenced by the distribution of the mineral matter in the coking coal and subsequently in coke. Since SiO<sub>2</sub> constitutes a major component of coking coal and resulting coke ash and is known to react with carbon and degrade coke, the interaction between SiO<sub>2</sub> – bearing mineral matter and coke are being investigated.

Coking coals with a wide variety of mineral-matter assemblages have been selected. The transformation of mineral matter during coking has been examined and quantified using X-Ray Diffraction (XRD). A computer-controlled scanning electron microscope referred to as Mineral Liberation Analyser (MLA) will be used to determine the size distribution and mineral associations. This size information will then be used as input for the development of a mechanistic model to estimate the extent of reaction between SiO<sub>2</sub> – based mineral matter and coke.

# EXPLORING THE USE OF ILMENITE AS A POTENTIAL OXYGEN CARRIER IN A CHEMICAL-LOOPING COMBUSTION PROCESS (CLC)

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## Project Summary

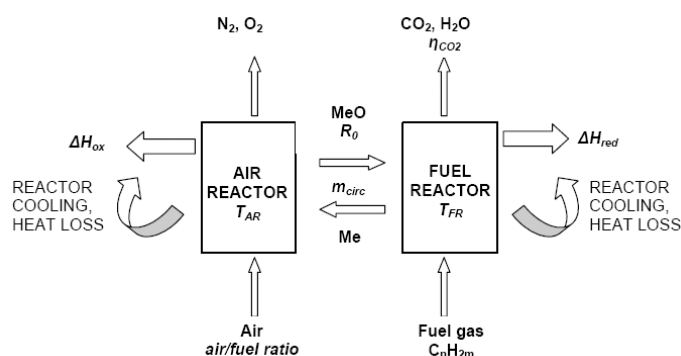
Observation of increasing concentration of CO<sub>2</sub> and the thereto suspected increase in Global warming has made prevention of CO<sub>2</sub> emissions from power plants a important part of research. Today mostly fossil fuels like coal, oil or natural gas are used in thermal power plants which yields substantial amount of CO<sub>2</sub>, capturing that with absorption and membrane separation process turns out to be cost intensive owing to their dilute compositions. This has lead researchers all over the world to explore CO<sub>2</sub> neutral fuels (Biomass) and redefine certain combustion processes making sure they concentrate CO<sub>2</sub> released whilst running at greater efficiencies.

In CLC, the CO<sub>2</sub> and the other combustions products are already separated in the combustion unity. Instead of combusting the fuel with air/O<sub>2</sub> solid oxygen carriers are used for reducing the fuel. The oxygen carriers are then regenerated in an oxidizing unit. This way the CO<sub>2</sub> released in the combustion unit is not diluted by excess air as in conventional combustion unit. Different metal oxides have been proposed for the CLC system like CuO, CdO, Mn<sub>2</sub>O<sub>3</sub>, Fe<sub>2</sub>O<sub>3</sub> and CoO. Generally these metal oxides are mixed with an inert for providing mechanical strength, attrition resistance and ion permeability for the oxides. A good CLC material should posses:

1. High mechanical strength
2. High rates of reaction and conversions
3. Sustainability to consecutive red ox cycles
4. Resistance to carbon deposition (while in reduction phase due to break down of fuel at high temperatures.

Research undertaken in our University is to explore the availability of Ilmenite (Natural ore of Iron) as a potential oxygen carrier. Abundance and cheap availability of this ore is the main driver for this research. The reactivity experiments will be done on TGA and will be compared to different commercially available metal oxides.

### Schematic representation of CLC:



## HEAT TRANSFER IN OXY-FUEL COAL COMBUSTORS

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### Project Summary

#### Background:

Oxy-fuel coal combustion is being seriously considered as a technology of reducing green house gas (GHG) emissions, by using pure O<sub>2</sub> (instead of air) mixed with recycle flue gas (mainly CO<sub>2</sub>) as a combustion medium for coal based power generation, to produce a concentrated CO<sub>2</sub> stream ready for sequestration. By doing this, the furnace gases have much higher levels of CO<sub>2</sub> and H<sub>2</sub>O, influencing the emissivity and consequently radiative heat transfer in these systems.

Based on the higher concentrations of CO<sub>2</sub> and H<sub>2</sub>O in combustion medium (optical path length, PpL exceeding 10atm-m) compared to air-case, the heat transfer assessment for oxy-case would require proper estimation of the gas radiative properties to incorporate into heat transfer models. Therefore existing gas radiation models for conventional air-firing (up to 10atm-m) need to be validated and/or modified for oxy-case by more accurate gas radiation band model.

#### Aim:

The aim of this research project is to develop methods to allow heat transfer assessment and design of oxy-fuel pf boilers in coal combustion.

#### Results So Far:

Computational Fluid Dynamics (CFD) was used to optimize existing air-fired boilers, and a great potential for using the tool in the design of oxy-fuel boilers as well as retrofit of existing boilers is foreseen. However, certain models used in existing CFD codes such as Weighted Sum of Gray Gas Model (WSSGM) need further development to work properly in such a gas environment.

Currently, a new set of gas radiation coefficients for the Grey Gas Model have been generated for PpL = 2 atm-m. Also, future studies include generating new model coefficients (sets) to account for higher optical paths (exceeding the PpL limits for air-combustion). Preliminary estimates show that the introduction of fourth gray gas improves the estimates of emissivities using WSGGM for large oxy-fired furnaces. FLUENT-CFD predictions are in good agreement when compared with the experimental measurements on pilot-scale tests on air and oxy-fired combustion.

#### Future Work:

In future, these new property results for oxy-fuel conditions will be applied to heat transfer model (CFD) for a retrofit study to compare with the experimental pilot-scale (~ 1 atm-m) measurements done and predict furnace performance for air and oxy-fuel systems and used as an input to the reference design of demonstration project (~ 5 atm-m) and also for scaling to power station furnaces (> 10 atm-m).

# EFFECT OF PYROLYSIS CONDITIONS ON STRUCTURAL TRANSFORMATION, AND THEIR COMBINED EFFECT ON BIOMASS COMBUSTION REACTIVITY

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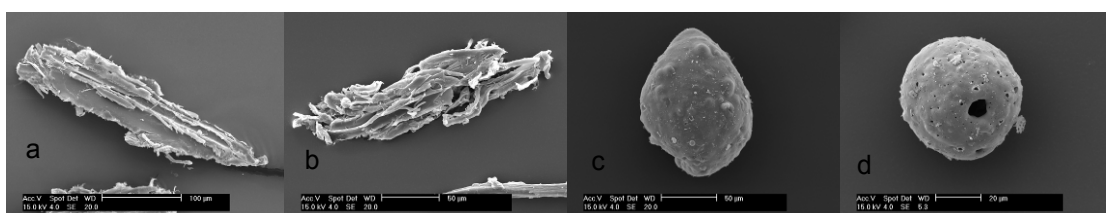
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## Project Summary

Fear of climate change and increasing carbon dioxide concerns have prompted a search for cleaner electric power generation systems. A thorough knowledge of biomass fuels, their properties and thermal conversion process (particularly the rate limiting char conversion step), is vital to successful design and development of such systems. Thermal conversion of biomass fuels occurs in two steps, (1) pyrolysis – release of volatiles and (2) char conversion.

It has been established in literature that pyrolysis conditions have a significant impact on structural transformations of biomass particles and on the reactivity of the resultant char. A recent study completed in 2004 found that biomass particles underwent similar structural changes to coal particles, and concluded that the gasification reactivity of biomass char cannot be studied without investigating the char morphology and structure evolution. It is the aim of this study to investigate the effect of the pyrolysis conditions on the char morphology.

Slash pine chars produced under various pyrolysis conditions have been observed to resemble the three generic coal char types. It has been found that heating rate alone affects the morphological evolution of the char. High heating rates favour the plastic deformation of particles and results in cenosphere chars, as shown in figure 1.



*Figure 1 – Slash pine raw and char particles from 75-106 $\mu$ m size fraction, (a) raw biomass particle, (b) char formed at low heating rate 1 $^{\circ}$ C/s & temperature of 1000 $^{\circ}$ C, (c) char formed at high heating rate 10 $^4$ -10 $^5$   $^{\circ}$ C/s & temperature of 800 $^{\circ}$ C, (d) char formed at high heating rate 10 $^4$ -10 $^5$   $^{\circ}$ C/s & temperature of 1000 $^{\circ}$ C.*

A mechanistic model will be developed, describing the process and pathway of char formation. This model will enable future designers to accurately predict the char types formed under various pyrolysis conditions. It will provide insight into the char reactivity and ash characteristics by utilising existing coal models for predicting char reactivity and ash formation.

## DIFFERENCES IN REACTIVITY OF PULVERISED COAL IN AIR (O<sub>2</sub>/N<sub>2</sub>) AND OXY-FUEL (O<sub>2</sub>/CO<sub>2</sub>) ENVIRONMENTS

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### Project Summary

#### Motivation and objective:

Oxy-fuel combustion technology has been developed to significantly reduce the emission of Carbon dioxide (a major greenhouse gas). Oxy-fuel combustion produces a concentrated stream of CO<sub>2</sub> ready for sequestration. The reactivity of pulverised coal during combustion in O<sub>2</sub>/CO<sub>2</sub> conditions is important for optimising furnace design for the oxy-fuel combustion technology. For example, when retrofitting an existing air-fired furnace with oxy-firing technology, good coal burnout should be obtained. The present study involves the measurement and comparison of char burnout of three Australian coals in a drop tube furnace at 1400 °C.

#### Experimental Parameters:

The oxygen concentration was varied in mixtures of O<sub>2</sub>/N<sub>2</sub> (air) and O<sub>2</sub>/CO<sub>2</sub> (oxy-fuel) in the range of 3 to 21% and 5% to 30% respectively.

#### Results:

Char burnout increased with the increase in oxygen concentration. Char burnout was enhanced in the oxy-fuel atmosphere, for all the three coals studied, and this enhancement is attributed to the char gasification reaction with the CO<sub>2</sub> present (*Figure 1* for Coal B).

Modelling of char combustion:

The char combustion rate  $q$  (the mass of carbon loss per unit external surface area per unit time) depends on the diffusion rate coefficient,  $k_D$ , the chemical reaction coefficient,  $k_R$ , the partial pressure in the gas,  $p_g$ , and at the char surface,  $p_s$ , according to the relation:

$$q = k_D (p_g - p_s) = A e^{-\frac{E}{RT_p}} p_s^n \quad \text{kg/m}^2\text{s}$$

The pre-exponential factor  $A$  of char was determined for various values of apparent reaction order  $n$ , in the range of 0 to 1, assuming an activation energy ( $E$ ) value of 71,000 kJ/kmol. The data suggests that there exists an optimal value of apparent reaction order (as shown in *Figures 2 and 3* for Coal B in air and oxy-fuel conditions respectively) which depends on coal and is less than 1. The reaction orders and pre-exponential factors obtained in the present study are tabulated in *Table 1*. Coal B showed significant differences in the values obtained. The results obtained in this study are used as inputs for char combustion sub-models of commercial CFD codes used in modelling air and oxy-fuel furnaces.

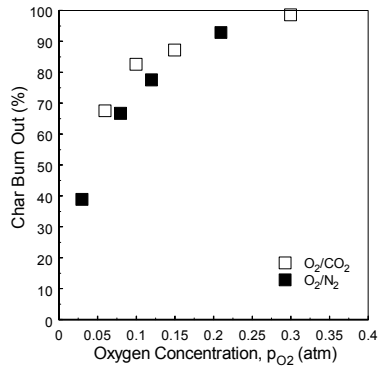


Figure 1

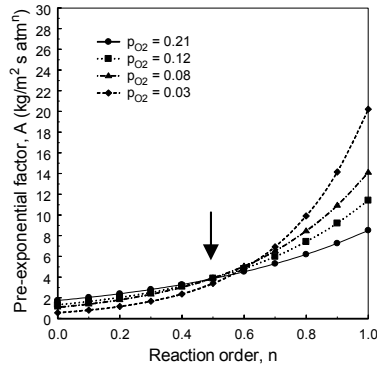


Figure 2

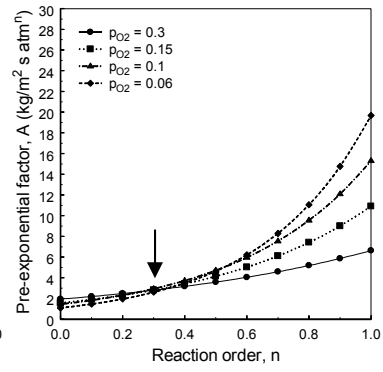


Figure 3

Table 1

Coal	Air atmosphere		Oxy-fuel atmosphere	
	$n$	$A$ (kg/m <sup>2</sup> s atm <sup><math>n</math></sup> )	$n$	$A$ (kg/m <sup>2</sup> s atm <sup><math>n</math></sup> )
Coal A	0.2	3.06 ± 0.07	0.2	3.19 ± 0.18
Coal B	0.5	3.89 ± 0.03	0.3	2.86 ± 0.08
Coal C	0.2	3.18 ± 0.10	0.2	3.40 ± 0.27

## OXIDATION OF METHANE IN MINE VENTILATION AIR USING POROUS BURNERS

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### Project Summary

Emissions of methane constitute around 17% of the total worldwide anthropogenic greenhouse gas emissions. About 10% of this total comes from fugitive emissions of coal mine methane, the primary source of which is the methane in the mine ventilation air (MVA) from underground mines. In Australia, fugitive emissions from underground coal mines contribute approximately 9 Mt of carbon dioxide equivalent, or about 1.5%, to the total national greenhouse gas emissions.

MVA emissions are characterised by very low methane concentrations (typically less than 1%) and high flow rates (up to 1900 m<sup>3</sup>/s for a large gassy mine), with significant long- and short-term fluctuations in both concentration and flow. These attributes constitute the major technical barriers to the capture and use of the methane in MVA. A number of solutions have been proposed, including flow reversal reactors and lean burn gas turbines, but a cost effective method of MVA mitigation has yet to be proven.

Porous burners are an advanced combustion technology whereby a premixed fuel/air mixture burns within the cavities of a solid porous matrix, rather than as a free flame at the burner exit, as is the case with conventional gas burners. The porous matrix serves as a means of recirculating heat from the hot combustion products to the incoming reactants, leading to higher flame speeds and extended flammability limits. This project will assess the feasibility of using porous burners for the oxidation of methane in MVA.

A pilot-scale porous burner has been designed, constructed and commissioned. The burner comprises a combustion chamber filled with a porous bed of alumina saddles, combined with an arrangement of external heat exchanger tubes for preheating the incoming fuel/air mixture. As part of the design process a computational fluid dynamics (CFD) model of the gas flow through the burner was developed. This was used to optimise the burner configuration to ensure that an even flow distribution could be obtained.

The oxidation of ultra lean methane/air mixtures has been demonstrated in the pilot-scale porous burner. Preliminary results indicate that it is possible to achieve complete combustion at methane concentrations below the lean flammability limit for a free flame (5% by volume in air). Measurements of the temperature profile along the burner, combined with exhaust gas analysis, show that combustion can be stabilised within the porous bed for a range of initial gas velocities and firing rates.

This project is ongoing and upcoming experiments will determine the complete operating range for the pilot-scale burner. Future work will look at reconfiguring the burner to further extend the lean limit, for example by altering the height of the porous bed or by selecting a more effective porous material. Additionally, the CFD model has been extended to include methane combustion chemistry, and will be used to investigate operational and scale-up parameters of significance to MVA oxidation.

# THE RELATIONSHIP BETWEEN ELECTRICITY AND GAS INDUSTRY IN AUSTRALIA

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## Project Summary

### Background:

Electricity and gas are two of the most important industries in the Australian energy context. Both industries have been undergoing reforms since the early 1990s. It is expected that these reform would improve the efficiencies of these industries and provide wider economic benefits. A review of these reforms suggests that they are being undertaken in isolation from each other, in total disregard of the relationship that may exist between these two industries. This research argues that the benefits of such reforms can be enhanced if one is able to take the relationship that exists between these industries into account in the design of industry reform programs.

### Objective:

Against the foregoing background, this research aims to examine the true nature of relationship between electricity and gas, with a view to propose a reform path for these industries.

### Methodology:

These relationships are examined through a historical analysis of both industries, from 1770 to the present. This examination focuses on the following aspects of both industries - physical, structural, ownership, and regulatory. This examination is then supplemented with econometric analysis at downstream and upstream levels, in national and state context. Inferences are drawn about the nature of relationship between electricity and gas on the bases of the above noted analyses.

### Main findings:

- Historically, there has been a corresponding relationship between these two industries. The availability of natural resources and politics have significantly influenced the evolution of these industries.
- Econometric analyses suggest that electricity and gas are weakly interrelated at upstream and downstream levels, especially in the national context. They are largely complementary at the national stage. While they also have complementarity at the state levels. The strength of complementarity however varies from state to state. This is due largely to the influence of state policies in regard to these two industries.
- There are contradictions between the findings of historical and econometric analysis. This suggests that there are limitations in the capacity of econometric analyses to capture institutions influences of industry evolution.
- This research also suggests that the true understanding of the relationship can only be gained by paying attention to the institution dimensions.

## A SUSTAINABLE ENERGY FUTURE IN BHUTAN: TRENDS AND STRATEGIES\*

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### Project Summary

**Aim:** The overall aim of my PhD research project focusing on Sustainable Energy Strategy Development for Developing Asian Nations is to develop a framework for a sustainable energy policy formulation and implementation for developing Asian nations. The PhD project also aims to assess best practice examples of sustainable energy strategies from industrialised nations (Australia and European Union) and to address the critical barriers to implementation in the developing nations' context. A specific part of my research focuses on Bhutan's sustainable energy future – trends and strategies and involves analysing Bhutan's development trends and appropriate strategies for sustainable energy development for the nation.

**Methods:** A significant amount of literature exists on natural resource management and biodiversity in Bhutan. However, literature that focuses on Bhutan's energy development strategy approaches is scarce. Accordingly, a review of Bhutan's energy resources and assessment of policy has been carried out. Information has been sourced via desktop literature review and via communication with government, non-government and international organisations active in Bhutan on energy and environment issues. From the review, Bhutan's energy development trends and strategies have been analysed.

**Findings:** Bhutan has shown a steep development trend in the last four decades. However, Bhutan faces major development challenges due to its setting as a landlocked country with a small economy and thus a small domestic energy market. This also results in higher costs for social services and the development of infrastructure. In addition, a lack of skilled labour and a lack of technical expertise also have been experienced. Despite the fact of tremendous accomplishments registered, particularly in the last two decades of development, Bhutanese institutions are still new and fragile, and the substantial challenges remain due to its high population growth and the *Middle Path* of development strategy. Bhutan possesses a unique approach to development via *Gross National Happiness* or the *Middle Path* of development which is grounded in Buddhist insights and aims to balance poverty alleviation, environmental conservation and development. In fact, striking a balance between tradition and modernity is the greatest future challenge of the nation. This is because liberalisation emanating from various levels of interaction with other nations although arguably beneficial for Bhutan is also gradually posing several challenges to the economy and the society.

Moreover, the major economic risk of Bhutan is its current high dependence on a one-country-one-commodity framework via hydropower which, tends to make Bhutan vulnerable to the pressures of development from across its southern border. About 90% of total electricity generated from hydropower schemes, which is sold to India, remains Bhutan's single major source of revenue. This eventually may damage the non-power trade sectors e.g. manufacturing and mining, and also non-trade sectors e.g. services and construction.

Decentralisation of both institutional settings and central Government control of administration should lead to effective public participation in decision-making and take greater local responsibility for

necessary infrastructure and services. Also the need for an umbrella policy framework has been recognised as necessary to facilitate a holistic approach to address nation's environmental issues. Despite the fact of early success of selected development projects, especially sustainable energy projects, a more comprehensive strategy is necessary to make these projects tangible and economically viable.

This research has also revealed that Bhutan's renewable energy sources (e.g. water and forests) which are indispensable for the nation's development are vulnerable due to environmental degradation and the adverse impacts of climate change. Appropriate measures in order to reduce potential climate impacts have been acknowledged globally and these have potential for implementation in Bhutan. Implementation of the Clean Development Mechanism (CDM) under the Kyoto Protocol is such a mechanism. Bhutan has already showed its capability in implementing this scheme via implementing a micro-hydropower CDM project. CDM aims to reduce emissions of anthropogenic greenhouse gases and contribute to sustainable development. Arguably, the example of Bhutan in implementing a CDM project proves this mechanism is operational. Even though Bhutan's contribution to global greenhouse gas emissions remain negligible, implementation of CDM project will contribute in mitigating climate change impacts indirectly and offer synergistic benefits to nation's sustainable development. This also could be seen as a showcase to the rest of the world.

It is hoped that Bhutan will deal successfully with external influences and will be guided by the experience from best practice to date such as with implementation of sustainable energy projects.

**Further Research:** Substantive research on strategic approaches to sustainable energy development for Bhutan will be pursued. This will include research on CDM projects in Bhutan to assess their contribution in Bhutan via offering synergistic benefits and how CDM policy and the mechanism will fit with the nation's development agenda particularly with reference relevant to sustainable energy projects.

**Dissemination To Date:**

Uddin, S. N., Taplin, R., and Yu, X., in press, Energy, environment and development in Bhutan, *Renewable and Sustainable Energy Reviews* <http://www.elsevier.com/>

Figure: Location of Bhutan



Source: Adapted from Uddin et al. (in press)

\*This research project is a part of the PhD research project '**Sustainable Energy Strategy Development for Developing Asian Nations**' commenced in February 2005 which focuses on Bangladesh, Bhutan, Thailand and Vietnam

# MESOPOROUS CARBON NANOCOMPOSITE FOR ELECTROCHEMICAL POWER SOURCES

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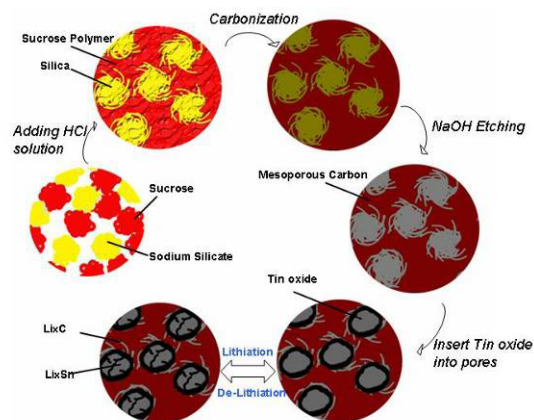
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## Project Summary

Mesoporous carbon (MC) materials are intensively studied recently since they are applied in many fields like gas purification, gas separation, catalysts and batteries. Herein, we use direct fabrication method to synthesize mesoporous carbon. Firstly, a nanocomposite of carbon and silica is prepared by the sol-gel method and then the silica framework is removed from the composite. The mesoporous carbon based nanocomposites were then prepared by reductive precipitation (for tin/MC) and microwave irradiation (for Pt/MC), respectively. The tin/MC nanocomposite exhibits reversible capacity of 358 mAh/g with good cyclability (96% of first reversible capacity remains after 200 cycles.) for lithium ion battery. The tin insets visibly occupy the meso-pores of the mesoporous carbons, and subsequently the normal tin anodes poor cyclability caused by tin metal volume expansion during the lithium intercalation and deintercalation is avoided. The Pt/MC nanocomposites as electrocatalysts for direct methanol fuel cells were also prepared. The platinum nanoparticles are decorated on the defect sites of the mesoporous carbons and tend to agglomerate, so the electrochemical catalytic properties are not as good as commercial Pt/C catalysts. The detail studies are carrying on in our laboratory. The typical tin/MC nanocomposite synthesis procedure is shown in the diagram:



## FUELLING AUSTRALIA'S TRANSPORT FUTURE

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### Project Summary

The near-term sustainability of fuels in Australia's transport systems with regard to continuing increases to domestic demand, decreasing domestic supply and uncertainty in world oil production is examined. With net demand for oil in Australia at over 130% of current domestic production (of which more than 95% is used for transport and set to increase) the current situation is unsustainable should there be significant problems in the international oil market. This is compared with hypothetical scenarios involving changes in energy supply and infrastructure both now and in the immediate future in an effort to determine what changes will be required for Australia to become self sufficient in meeting its liquid transport fuels demand.

Current usage trends in Australia are compared with domestic and global production both now and into the future using a variety of different projections including those from ABARE and from extrapolative methods such as Hubbert linearisation. Current usage trends are studied to determine the major consumers and those for which consumption patterns are most easily modified – the “low hanging fruit”.

The assumed scenario is a 25% shift of personal automotive transport to non-liquid fuel energy storage such as compressed air or batteries, along with a shift of 25% of interstate freight transport from road to rail over a five-year timeframe. Preliminary data indicates that this scenario will not achieve self-sufficiency, but will see a significant reduction in demand of over 10%. This mainly appears due to the low level of shift to alternate fuels and that only approximately 50% of Australia's overall oil consumption is affected by this scenario. Greater incorporation of other major fuel consumers, including agriculture and mining, into the scenario can be expected to show more substantial results.

Further work is being conducted to determine the measures and shift to alternate fuels necessary to achieve an energy self-sufficient domestic transport system, the physical and technical infrastructure changes necessary to support this scenario and others, and the difference in life cycle Greenhouse Gas Emissions that will result.

## SYSTEMS APPROACH TO EVALUATING RENEWABLE ENERGY PROJECTS

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### Project Summary

The adequacy and benefits of renewable energy (RE) projects are commonly evaluated by their economic performance, their efficiency, as well as their ability to mitigate carbon dioxide emissions. However, while an individual technology may show very good performance in these areas, the fact is that RE generators do not operate in isolation. While their main requirement is to fulfil a specific demand (e.g. base load energy, peak demand, distributed generation), they also have to be compatible and competitive within the system they enter. We thus propose that the introduction of new technologies and facilities is best evaluated by analysing the performance of the entire system, as opposed to just the performance of the RE project. This is done by constructing a model of the system including the embedded RE project and optimising with regards to a range of economic, environmental, as well as social objectives. The model is dynamic to assess the response of the system over time. By taking this approach, it provides a more comprehensive evaluation of the adequacy and sustainability of the project. The system view can also give insights into how the project could be adapted to improve the expected performance, or if an alternative project would be more successful.

The approach will be demonstrated with a case study dealing with power generation from bagasse in South Africa. The proposed project deals with the viability of a dedicated power station using bagasse as a fuel to generate power for the grid. To determine whether this is the best way forward, we compare this option to a variety of alternatives available:

- The bagasse can be used to generate **distributed power**, generated at the sugar mills, which are situated close to poor areas with some having less than 50% electrification.
- The bagasse can instead be **co-fired** at an existing coal-fired power station.
- The bagasse can be **co-gasified** with coal at an existing Fisher-Tropsch plant.
- The bagasse can be used for **ethanol** production for bio-fuel.

Apart from these energy options, there is also demand for bagasse by the pulp and paper industry, which would have to switch to more expensive wood fibre if bagasse became unavailable. The options will be assessed with regards to their potential to electrify rural households, total NPV and CO<sub>2</sub> abatement.

## THE EFFECT OF SOCIAL FACTORS ON THE EVOLUTION OF ENERGY SYSTEMS

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### Project Summary

Energy research and development faces real challenges with global energy demands rapidly increasing and the current reliance on fossil fuels proving to be unsustainable. Many argue that a radical transition of our energy systems is required in order to be able to provide energy for future generations. The magnitude and direction of such a transition depends the strategic behaviour of the companies, and the governmental and non-governmental organisation that determine our current energy systems. Namely, it is the organisations that decide whether new innovations will be implemented, new infrastructures will be built or new research areas will be explored. Although more than \$US 9 billion annually is spend on energy research and development globally, hardly any research focuses on how organisations in energy systems make decisions and how this affects the evolution of the system as a whole. Furthermore, a systems perspective is often lacking, although the sustainability of energy system depends on the interconnections between the organisations rather than their individual performances. Thus, an understanding of how strategic behaviour of companies and governments affects the evolution of energy systems is essential to making a transition towards a sustainable energy system reality. Such understanding could be provided by models that provide insights in how strategic behaviour of organisations affects the evolution of energy systems. Recent developments in the area of agent-based modelling provide tools in which the effects of strategic behaviour can be explored.

For many years it has been assumed that organisations behave as rational entities, which make strategic decisions about the implementation of new technologies on the basis of economic indicators, such as the internal rate of return (IRR). However, more recently economic, sociological and psychological research have found that organisations, faced with the inherent uncertainty about the future, largely base their decisions on social constructs, such as loyalty, trust, status and social norms. A model is developed that explicitly models the role of social factors in strategic decision making processes of organisations and with which it is possible to explore the evolution of energy systems. These models can help in creating an understanding of what drives the networks and how technologies, strategies or policies can be developed that eventually will transform our energy system into a more sustainable one.

The development of these models is demonstrated in a case-study of a regional energy system in South Africa. Currently, electricity is provided by a national energy provider on the basis of coal, however, the fast increasing energy demands in the region requires that alternative energy resources should be considered. Bagasse, a waste product of the sugar industry, is one of the potential alternatives as an energy source, however, is currently locked in by sugar industries that burn bagasse inefficiently for local heat demand. The model explores the potential for different generation technologies and how these are affected by social factors driving the decision making processes of organisations involved. The insights are subsequently used for the development of policies instruments to guide the transformation of this energy system.

## PRODUCTION OF H<sub>2</sub> FROM BIOMASS COUPLED WITH CO<sub>2</sub> CAPTURE

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### Project Summary

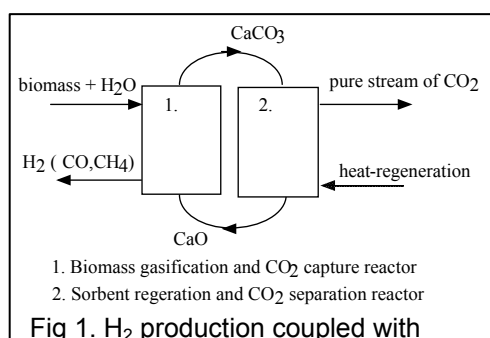
This work investigates a novel H<sub>2</sub> production process from biomass, coupled with a CO<sub>2</sub> capture and separation cycle.

An ideal vision of a futuristic H<sub>2</sub> energy economy is one whereby H<sub>2</sub> and electricity are the only energy carriers, both produced from renewable and environmentally benign resources. H<sub>2</sub> would be used for all the applications where fossil fuels are currently employed, including transportation and power generation. However, there are ideological and technical challenges in moving towards a H<sub>2</sub> energy system. One major challenge, and the focus of this research, is the production of sufficient quantities of H<sub>2</sub>.

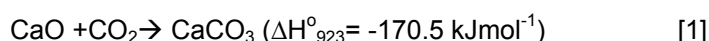
Currently, H<sub>2</sub> is produced for use in the chemical and petrochemical industries and fossil fuels are typically exploited for this production, which results in significant CO<sub>2</sub> emissions. Hence, there is a need for novel H<sub>2</sub> energy production pathways, utilising renewable resources and eliminating CO<sub>2</sub> emissions. In this context, this work examines the production of H<sub>2</sub> via the steam gasification of biomass. This process, when coupled with CO<sub>2</sub> capture, has the potential to be a net sink of CO<sub>2</sub> from the atmosphere.

We began this research by exploring the hypothesis: "Biomass represents a renewable resource for the sustainable production of H<sub>2</sub>". To test this hypothesis, we considered the currently under-utilised biomass resources in Australia, including: forestry and logging wastes and agricultural wastes and residues. Based on a back of an envelope calculation, we show that there are sufficient biomass

resources to produce enough H<sub>2</sub> to fuel all the buses in Australian capital cities 30 times over for 1 year. This simple analysis clearly demonstrates the potential for producing H<sub>2</sub> from biomass.



The proposed process, involving the gasification of biomass with steam, leads to the production of a mixture of gases including: H<sub>2</sub>, CO, CO<sub>2</sub>, CH<sub>4</sub> and small quantities of tar and ash. In order to enhance the H<sub>2</sub> concentration in this product stream, CO<sub>2</sub> is captured in situ, utilising the carbonation reaction, according to Eqn. [1]:



The fundamental idea is that the removal of CO<sub>2</sub>, in the form of solid CaCO<sub>3</sub>, alters the chemical equilibrium, promoting the output of H<sub>2</sub>. Using a thermodynamic equilibrium model we have demonstrated, when CaO is present, an improvement in the H<sub>2</sub> concentration from 58%-vol to 83%-vol. When the sorbent has been converted to CaCO<sub>3</sub> it can be regenerated, by pushing the carbonation reaction (Eqn. [1]) in the reverse direction, with the application of heat. The production of a pure stream of CO<sub>2</sub> is then available for industrial processes or for a range of sequestration technologies. A simple

sketch of this cyclical process is shown in Fig. 1. A fluidised bed reactor is most suitable for this process, allowing for very good contact between the reacting gas and solid species (biomass, CaO), promoting both high biomass conversion and efficient CO<sub>2</sub> capture.

A major limitation of the process is the incomplete conversion of the CaO sorbent to CaCO<sub>3</sub> and the further decay in the reactivity through multiple CO<sub>2</sub> capture and release cycles. This deterioration in the sorbent performance is due to an irreversible change in the pore structure that occurs as the reaction progresses. In order to address this problem we have designed a tailored CaO CO<sub>2</sub> sorbent, to achieve superior CO<sub>2</sub> capture performance. Based on preliminary tests, we have demonstrated an increase in the conversion of the tailored CaO to 86%, compared to 68% with a commercially available sorbent. Furthermore, this enhanced reactivity is maintained for a number of reaction cycles. Further work is required in order to demonstrate this improved reactivity for a larger number of reaction cycles and to optimise sorbent performance in the presence of tars and char formed during biomass gasification.