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Case Study into Renewable Energy in Australia

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Acronyms used

A3P	Peak national body for Australia's plantation products and paper industry.
ABARE	Australian Bureau of Agricultural and Resource Economics
AGO	Australian Greenhouse Office
ANSTO	Australian National Science and Technology Organisation
ARC	Australian Research Council
AWEFS	Australian Wind Energy Forecasting System
CHP	Combined heat and power
CMHT	CSIRO Molecular and Health Technologies
CET	CSIRO Energy Technology
CIGS	Copper-indium-gallium-diselenide solar cells
CRC	Cooperative Research Centre
EGS	Enhanced geothermal systems
DSC	Dye-sensitised solar cell
EU	European Union
GHG	Greenhouse gas
GW	Giga-watt or 1,000,000,000 watts
GWh	Giga-watt hours
HDR	Hot dry rock geothermal systems
ICOS	International Consortium for Organic Solar Cells
JVAP	Joint Venture Agroforestry Program
MDF	Medium density fibreboard
MRET	Mandatory Renewable Energy Target
MW	Mega-watt or 1,000,000 watts
MWp	Peak mega-watt
NAFI	National Association of Forest Industries
NCRIS	National Collaborative Research Infrastructure Strategy
NEMMCO	National Electricity Market Management Company
NHMA	National Hydrogen Materials Alliance
OPV	Organic photovoltaics
PV	Photovoltaic
RECs	Renewable Energy Certificates
RIRDC	Rural Industries R&D Corporation
TWh	Terawatt-hour, or 1,000,000,000,000 watt-hours
UK	United Kingdom
UQ	University of Queensland
UNSW	University of New South Wales
USA	United States of America

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Executive Summary

As Australia's national research organisation, CSIRO has a range of capabilities directed at maintaining an internationally competitive and sustainable energy industry. In 2006-07 CSIRO's total budget for renewables R&D was approximately A$14 million, largely via the Energy Transformed National Research Flagship.

The importance of energy security, and need to lower greenhouse gas emissions has been recognised by Australia, illustrated by the Mandatory Renewable Energy Target (MRET) and government support for low emission and renewable energy technologies.

This submission outlines the potential and state of development, CSIRO's research and capabilities, and collaboration in the Australian innovation system for the bioenergy, geothermal, wind, energy storage, solar photovoltaics, solar thermal and hydrogen energy sectors.

Bioenergy technologies are at an early stage of development. However the Australian environment is suited to bioenergy production, which currently makes a very significant contribution to the MRET, with potential to fulfil up to 90% of this target. Additional benefits from bioenergy production could include carbon sequestration and salinity mitigation. These require further investigation to determine the full benefit of bioenergy development. Australian innovation in biofuels involves a relatively large number of small industry players, although some CRC and state government activity is also underway. CSIRO brings a multidisciplinary approach to bioenergy research, providing options, technologies and pilot scale implementation. To understand the full potential of biofuels for Australia further work is required in developing alternative scenarios for Australia, efficient energy generation units and co-product approaches.

Solar thermal energy has many advantages, but is yet to see the reduction in costs that comes with technology development. Consequently it remains more costly than wind energy and lags in development by around 10-15 years. There is no technical reason why a large solar thermal power plant could not be operating within 3-4 years in Australia. There is a cost gap at the present time and appropriate incentives for both R&D and construction activities will be needed to ensure Australia maintains a leading position in this global growth industry. CSIRO has a significant solar thermal research program, including the recently developed National Solar Research Facility in Newcastle. Along with Australia's other major R&D provider in this sector, ANU, CSIRO is active in international collaboration for what should become in time a very cost effective and profitable energy export opportunity for Australia.

Solar photovoltaics is again a relatively young technology with the global market dominated by first generation technology, and expected to remain so for the next five years or so. Internationally some second generation technologies (such as copper-indium-gallium-diselenide solar cells) are in late development stages and should provide more cost effective options. "Third" or "next" generation photovoltaics have potential to overcome cost effectiveness barriers, and this is where CSIRO's R&D efforts are focussed, particularly in the area of organic photovoltaics (OPV). This focus is based on less capital and energy intensive production methods which should produce an affordable and clean solar electricity technology. There is widespread collaboration in Australia on next generation solar technology, involving industry, universities and CSIRO to overcome current barriers for uptake of solar photovoltaic technologies.

There are three important kinds of ***geothermal*** energy systems: high temperature hydrothermal/ volcanic systems not generally found in Australia; low temperature hydrothermal systems such as Australia's Great Artesian Basin; and Hot Dry Rock and Enhanced Geothermal Systems currently which form the bulk of Australia's geothermal investment. The Australian industry is in formative stages, although investment is buoyant in geothermal companies and technologies are often shared with other sectors such as petroleum. Worldwide R&D for this sector is generally attuned to local conditions, thus collaboration is geographically restricted. In Australia universities, states and commonwealth agencies such as CSIRO, are working together to address new technologies for local conditions. CSIRO's research, in partnership with universities, addresses both the extraction of geothermal energy in the Australian environment, and the processes of conversion to electricity.

Wind energy is plentiful, renewable, widely distributed, and reduces toxic atmospheric and greenhouse gas emissions if used to replace fossil-fuel-derived electricity. Wind energy is a significant

player in the renewable energy field and is a significant contributor to MRET. Australia's challenges are not in wind turbine technology, but in location of developments and integration into the electricity grid structure. The development of the Australian Wind Energy Forecasting system (AWEFS) collaboration under the auspices of the National Electricity Market Management Company (NEMMCO) recognises the significant potential for wind energy in Australia and brings together Australian R&D providers. CSIRO's activities have focussed on locating and quantifying wind resources, and addressing the intermittency issues of wind generation. The Energy Transformed National Research Flagship is addressing energy storage issues to address intermittency.

Hydrogen energy is only just entering the energy mix via demonstration projects, given its relative infancy. Currently, cost effectiveness and little or no demand limits the feasibility of hydrogen energy, although costs are expected to fall with input from R&D. As a member of the National Hydrogen Materials Alliance collaboration (a National Flagship Collaboration Research Fund), CSIRO is contributing to a collaboration with 11 Australian universities and ANSTO to develop hydrogen generation and storage technologies.

In Australia, the application of renewable energy has not achieved the levels reached in some other parts of the world. This is because Australia has an international advantage in our abundant reserves of fossil fuels consisting mainly of coal and gas. The well-managed exploitation of these resources has given us one of the most cost effective energy supply sectors in the world. This has limited the incentives for the wide spread take up of renewable energy technologies, as these technologies under present energy pricing conditions, are more expensive than renewable energy options.

However, as Australia confronts the need to operate in a lower carbon emissions future, the role of renewable energy will come increasingly into focus. This is especially the case as it is now certain that there will be a price of carbon emissions in the short term, most likely through a carbon trading scheme. Depending on the price of carbon emissions over time, the gap between renewable and fossil energy prices will narrow and this will make some renewable energy technologies more cost competitive in our future energy mix.

While wind energy and biofuels currently appear to have the best short to medium term potential for addressing the need for renewable energy generation in Australia, other less developed sectors such as third generation solar photovoltaics and geothermal energy, based on hot, fractured rocks, have potential to contribute more in the longer term, with hydrogen energy so early in development that an assessment of the real potential is difficult.

In all cases, R&D to address barriers to uptake such as cost effectiveness and integration with the electricity grid is ongoing in the Australian innovation system and will ultimately support the required development of a secure, cost effective energy supply for Australia's future.

1. CSIRO's Role and Relevance

CSIRO is Australia's national science agency and one of the largest and most diverse scientific research organisations in the world. CSIRO research delivers solutions for agribusiness, energy and transport, environment and natural resources, health, information technology, telecommunications, manufacturing and mineral resources.

Public research organisations contribute to national wellbeing different ways. For CSIRO, the focus is on delivering scientific solutions direct to Australian industry and communities, while building Australia's science base.

CSIRO adopts a systematic and deliberate approach to managing its research portfolio to:

- focus CSIRO skills and energies on the most important issues for Australia;
- continue to increase the impact and relevance of CSIRO science;
- maintain an appropriate balance between all the roles and responsibilities of CSIRO; and
- ensure the wise investment of taxpayers' dollars (our appropriation funding).

The approach is comprised of two major components. In the first phase, the senior executives of the organisation, taking into consideration a large array of internal and external factors, translate CSIRO's strategy into medium term investment priorities. Research Divisions and National Research Flagships then respond to these high level directions through an iterative process to give effect to required directional shifts and deliver specific outcomes and develop capabilities.

CSIRO has a wide range of research capabilities directed at maintaining an internationally competitive and sustainable Australian energy industry, including maximising Australia's options for renewable energy generation. It has internationally renowned and interdisciplinary expertise in a variety of relevant areas.

Based on its science investment process, CSIRO's total budget for renewables R&D was approximately A$14 million in 2006-07. This research covers the areas of wind, solar thermal, organic photovoltaics, energy storage, energy management and distributed energy. Much of this work is conducted through the Energy Transformed National Research Flagship.

CSIRO established the Energy Transformed National Research Flagship to respond to environmental and efficiency challenges facing the energy sector. Collaboration with national and global partners, seeks to deliver energy solutions for a sustainable future.

Two of the major contributors to greenhouse gas (GHG) emissions are the stationary energy and transport sectors. Aiming to retain cost-efficiency of power supply, the Energy Transformed Flagship identified the following industry-focused research project themes:

- Energy Futures;
- Low Emission Electricity;
- Low Emission Transport;
- Distributed Energy.

Energy futures research aims to identify optimum sustainable energy pathways and supply information to the energy sector regarding current research in this field. The remaining themes focus on technological innovations to halve GHG emissions and double the efficiency of Australia's new energy generation technologies.

Flagship research will:

- create a national energy model developed in response to the needs of industry, government and the community;

- develop and implement technologies that eventually lead to zero-emission power generation from fossil fuels and large-scale hydrogen generation; and
- decrease reliance on traditional sources of transport fuels through the development of alternative fuels. These include biofuels and increase vehicle efficiency through developing technologies for hybrid vehicles leading to the eventual transition to hydrogen vehicles.

Progress in these areas will ensure that Australia is well advanced in its capacity and capability to embrace the hydrogen economy later in the 21st century.

CSIRO has been developing new tools, technologies and frameworks to improve Australia's assessment and management of the economic, social and environmental implications of Australia's energy demand. CSIRO's research is firmly grounded in close partnerships with industry, government, university and community groups.

2. Introduction

Secure energy supply is essential for economic growth and to maintain living standards. Australia, in line with global trends, has increasing energy consumption, with current ABARE projections indicating fossil fuel will continue to provide the majority of Australia's energy in 2020[1]. While Australia's reserves of fossil fuels are significant, renewable energy resources are also abundant.

Australia recognises the need to lower greenhouse gas emissions and is taking substantive action to achieve this, having allocated some A$2 billion as part of a comprehensive domestic action program to address climate change. Australia has a policy objective of limiting greenhouse gas emissions to 108% of 1990 levels by 2008-2012.

In order to help achieve these objectives, the Australian Government set a Mandatory Renewable Energy Target (MRET[2]), and is supporting development of low emission technologies in order to meet this target. On 15 June 2004, the Australian Government reconfirmed its commitment to the MRET scheme at the current level of 9,500GWh by 2010. This announcement formed part of the Government's Energy White Paper – Securing Australia's Energy Future[3].

This submission outlines the potential, state of development, CSIRO's role and current R&D in the renewable energy sectors of bioenergy, wave, tidal, geothermal, wind, solar thermal and hydrogen.

3. Bioenergy

Introduction

Bioenergy is produced by the release of stored chemical energy contained in fuels made from biomass, stored by the photosynthetic activity of plants. It is not a new concept, beginning with the controlled use of fire to provide heat, light and cooking. The production of prepared biofuels also dates to ancient civilizations that made metal instruments in forges that burned wood in the form of charcoal and used liquid biofuels in the form of animal fats or vegetable oils for lamps.

Current status in Australia and globally

With the exception of firewood[4], the modern bioenergy industry is in its infancy in Australia. In order for bioenergy to become a viable renewable energy source a broad approach across the agriculture, forestry, waste and energy industries will be required. Australia has one of the world's highest ratios of land area to population and so is potentially suited to bioenergy approaches. However given the high ratio of arid lands, poor soils and uncertain water supply, further scenario development and investigation is required. It should be noted that bioenergy is closely related to other major national challenges for Australia. For example increasing biomass production to continuously supply a new bioenergy industry would sequester large amounts of atmospheric carbon dioxide if the biomass energy were used as a substitute for fossil-generated energy (this will become increasingly important under the newly announced carbon trading arrangements). It is also estimated by Bartle[5] that if all of Australia's electricity demand was generated from biomass grown in Western Australia, it would significantly reduce salinity issues. On the other hand, widespread biomass production may also reduce water runoff to rivers. The introduction of large scale biomass production system therefore requires comprehensive assessment so as to obtain multiple benefits and minimise any negative impacts.

In terms of biomass for electricity generation, Hague *et al*[6] identified a number of ways in which biomass can be used in order to generate electricity:

- direct combustion (biomass fired equivalents to coal fired power stations);
- co-firing with coal (addition of up to 10% biomass in coal fired power stations does not require any modification of equipment);
- gasification (heating in the presence of oxygen to produce a combustible gas);
- slow pyrolysis (heating in the absence of oxygen to produce "bio-oil"); and
- cogeneration (production of both heat and power also known in literature as CHP or Combined Heat and Power).

Countries such as Finland and Sweden are already using waste wood and plant material in a sustainable and economically viable manner for the production of fuel in the generation of electricity using new, efficient dedicated biomass power stations. 16% of Sweden's electricity is currently generated from wood based fuels[7].

The potential generation models identified for Australia by Raison[8] were:

- co-firing in large coal-fired power stations, though the cost of transport to relatively few very large power stations may be a limiting factor;
- establishment of a few medium to large (10 to 50MW) direct combustion power stations located in major forest areas;
- a larger number of 1 MW power plants producing energy and a range of co-products. An example of this would be the pilot plant constructed to process oil mallee in Narrogin in Western Australia. This 'biorefinery approach' to biomass processing and bioenergy is already a key part of chemical pulping and sugar production. In the future, the principle needs to be expanded to include a wider range of higher value products such as bulk chemicals and pharmaceuticals from biomass;
- a large number of small (<0.5MW) distributed generation plants for remote and regional areas. These could be small scale combinations of gasifiers and microturbines.

Biomass is also being used by wood processing plants (often bark and waste wood), chemical pulping plants (lignin 'black liquor' in chemical recovery plants) and sugar processing plants (bagasse) for both process heat and electricity. For example, the Laminex MDF production plant in Gympie, Queensland has a 5MW cogeneration plant fired with wood waste and bark.

A recent snapshot of the current role of bioenergy in the electricity sector was provided by Rossiter[9], who showed that biomass (in this case including landfill gas and sewage) was a major contributor to the MRET, supplying 41% of power plants, and 25% of Renewable Energy Certificates overall, with an estimated investment of $950 million to October 2006. 14 million Renewable Energy Certificates were from accredited power stations with approximately 2.7 million of these from bagasse, wood waste and black liquor biomass sources. Renewable Energy Certificates (RECs) are an electronic form of currency initiated by the *Renewable Energy (Electricity) Act 2000.* RECs are created by registered persons, validated by the Office of the Renewable Energy Regulator, traded between registered persons, and eventually surrendered to demonstrate liability compliance against the requirements of the MRET.

There are opportunities for bioenergy production from biomass both for electricity production and liquid biofuel production in Australia. In the short-term these opportunities will be met on a relatively small scale mainly by processing waste products. In the medium term (and to avoid depletion of food crops) large scale substitution of non-renewable fuel sources may be from lignocellulosic biomass from agri-residues and forestry or from algal based production of biodiesel. The production of this biomass has the added benefit that it is also a potential source of biosequestration of atmospheric carbon dioxide.

Raison estimated that there is a maximum of 16 million m^3/yr of wood potentially available for electricity generation in Australia. This material could meet approximately 90% of the current MRET, though this includes native forest residues. From a more recent study performed by CSIRO for the RIRDC[10], the conservative amounts of electricity that could be potentially produced from biomass (without impacting on food supply) are summarized in the table below. These amounts do not include electricity generation from crop residues, which offer similar amounts of biomass again, or black liquor.

Conservative estimates[11] of electricity production from biomass resources in Australia
(summarised table, not including crop residues)

Feedstock	Reasonable available fraction of Australian production (Mt)	Preliminary Electricity Generation figures (TWh)
Plantation material and wood waste		
Sawlogs and pulpwood	14	28
Urban wood waste	30% recovery of 3.3 - 4	
Waste from wood processing facilities	50% of 1.3	1.3
Plantation residues - current	50% of 2.1	3.1
Native Forest residues and Firewood		
Native forest residues	50% of 2.7	4.1
Firewood	10% of 6.0	0.5
Native forest thinning	100 % of 2.5	4
Future biosequestration and hardwood plantations		
Future mallee-eucalypt crop	100% of 2-100	18
Future hardwood plantation growth	25% of pulpwood and 50% of harvesting residue of 14	6

This study suggests that 41 TWh of electricity could be generated from existing woody material and over 20TWh from future plantation expansion and biosequestration or salinity remediation plantings. This does not include electricity generation from agri-residues.

Future development of the Australian biofuels industry requires underpinning research to develop:

- alternative biofuel scenarios in Australia (including sustainability and environmental impact) and the key technologies for inclusion in the options for supply;
- new, efficient and sustainable biomass energy generation units which are matched in size to the available biomass resource; and
- understanding of what co-product (biorefinery) approaches should be developed for electricity, ethanol or biodiesel.

CSIRO's research and capabilities

CSIRO has new and developing capability and research in two main areas: electricity generation and liquid biofuels. The second of these relates to transport fuel and is outside the scope of this enquiry. For information on biofuels for transport please refer to the *Report into Australia's future oil supply and alternative transport fuels by the Senate Standing Committee on Rural and Regional Affairs and Transport*[12] or *Biofuels in Australia: issues and prospects*[13].

CSIRO is providing multidisciplinary, multi sector biofuels research to provide options, technologies and pilot-scale implementation. CSIRO's recent report *Biofuels in Australia: issues and prospects*[13] was commissioned by RIRDC (Rural Industries Research and Development Corporation) and the National Farmers Federation and provides a multidisciplinary view of Australian biofuels situation.

CSIRO's Division of Energy Technology provides capabilities in the energy generation aspects of bioenergy, while the Divisions of Sustainable Ecosystems, Land and Water, Ensis[14], Entomology and Plant Industry are home to many of the integration skills and tools to pull together disparate approaches and data. They have many of the skills for impact assessment of current and future biomass production systems in terms of hydrology, biodiversity etc. at a range of scales. They also have modelling and experimental approaches to predict the production capacity of a wide range of current and future crop- or wood-based biomass production systems.

Current CSIRO research in biofuels includes:

- sustainable biomass production including biomass availability, logistics and supply models;
- sustainability factors and environmental impact of raw materials and processes for biofuels (local, regional and global scale and covering water and biodiversity values);
- fuel pelletisation from residues;
- segregation of waste streams;
- pre-processing of biomass to produce consistent and effective fuel; and
- production of liquid fuels from biomass using enzymatic, algal, thermochemical and fermentation approaches.

Collaboration in the Australian Innovation System

Bioenergy Australia[15] was established in 1997 as a government-industry forum to foster and facilitate the development of biomass for energy, liquid fuels, and other value added bio-based products. Its founders were a core of Federal Government organisations with the objective of providing the focus and a forum for bioenergy development in Australia. Since its formation the membership of Bioenergy Australia was expanded to 45 members from both government and industry. It is concerned with all aspects of biomass and bioenergy, from production through to utilisation and its work embraces technical, commercial, economic, societal, environmental, policy and market issues. This collaboration includes R&D providers and facilitates knowledge sharing in this relatively young and small sector. Many members are industry players who have done some very good, although mostly small or enterprise scale research, although scoping papers and case studies on opportunities for bioenergy have been produced by A3P[16], NAFI[17] and other industry associations.

The CRC for Plant Based Management of Dryland Salinity (in which CSIRO is a partner) has done considerable work on Australian bioenergy prospects and will continue to do so under auspices of the new CRC for Farm Futures. NSW State Forests (now known as Department of Environment and Conservation) have also done some work and NSW Department of Energy, Utilities and Sustainability put out a *NSW Bioenergy Handbook* in 2005[18] – a compilation of research.

The Joint Venture Agroforestry Program (JVAP)[19] has funded projects mainly quantifying biomass supply and desk studies, for example the *Bioenergy Atlas of Australia*[20] and *Forests, Wood and Carbon Balance*[21].

There is a range of emerging industry opportunities around biomass energy production technologies, such as:

- the Rocky Point Sugar Mill year round co-generation plant[22];
- Verve Energy pilot plant for mallee processing into charcoal, activated carbon and power (using CSIRO licensed technology);

- Auspine Ltd's investigation of a 60MW biomass fuelled power plant in South Australia[23];
- Sugar Research Institute improving the effectiveness of boiler efficiency in sugar mills[24]; and
- wood pellet, energy production and charcoal production by Bioforest Ltd[25].

4. Solar Thermal

Introduction

Solar thermal technologies use the sun's energy to heat a fluid. The hot fluid can be used simply for hot water, as in domestic solar hot water found on many roofs. However by concentrating the sun, higher temperature fluids can be generated which can then be used for power generation. Given that nearly all the world's electricity comes from first producing a hot fluid (whether coal, gas or nuclear), solar thermal integrates well with existing and future power generation technologies.

The advantages of solar thermal power are:

- it is modular and scaleable and therefore has the capacity to supply very large quantities of electricity;
- storage can be integrated within the process, so that intermediate and potentially base load power can be provided;
- the land area required is not large. A square of approximately 45km x 45km could contain enough solar collector area to supply all of Australia's present electricity requirements;
- the collectors are based on bulk commodity materials. There are no exotic or rare materials required that might otherwise lead to cost increases upon mass production; and
- it is based on the world's largest sustainable energy resource.

Current status in Australia and globally

Nearly 350MW of solar thermal power stations have been operating in California feeding into the electricity market for over 20 years. This is enough to supply approximately 130,000 homes. Solar thermal technology does work, and can do so at a large scale. The major need is for development to improve efficiency and reduce cost.

The Californian plants were built in the 1980s in response to a sharp rise in oil and fuel prices in the late 1970s. Few new plants were built in the 1990s, as the cost:benefit favoured large plants. With low fuel prices, and climate change not a major driver at that time, the risk associated with large plants made them an unattractive proposition. Over the last few years there has been a global resurgence in solar thermal power. Incentives in California and Spain have led to those jurisdictions seeing new plants opened and significant industry activity.

A recent study into the status of solar thermal technology for the World Bank[26] concluded the recent global activity and investment by major international construction companies could lead to a significant rollout of the technology in sun belt countries. It is worth noting that countries such as Germany are among the largest investors in this technology due to the potential for export of the technology and knowledge.

The most pressing need for the technology is cost reduction through efficiency improvement and new collector designs that lend themselves to mass production by the manufacturing industry. Presently, the cost is above that of wind energy, but solar thermal has not yet benefited from the cost reductions that will come through parallel paths of R&D, and the rollout of successively larger plants. The state of global investment in solar thermal, and the technology cost, is roughly where wind energy was some 10-15 years ago. In that time, wind energy costs have dropped by more than 50%, and it is now internationally a huge and self-sustaining energy industry. A similar cost reduction path is envisaged for solar thermal, being, involving, from an engineering sense, many of the same facets of the manufacturing industry. However solar will tend not to suffer the same sort of site limitations. As a consequence, the future costs for solar thermal power are anticipated to be one of the cheapest renewables, and competitive with other zero emission forms of power.

There is no technical reason why a large solar thermal power plant could not be operating within 3-4 years in Australia. There is a cost gap at the present time and appropriate incentives for both R&D and construction activities will be needed to ensure Australia maintains a leading position in this global growth industry.

CSIRO's research and capabilities

Solar thermal power is now a significant program within CSIRO and will grow strongly over the next few years with new projects and personnel. CSIRO has established a fully-equipped and instrumented National Solar Energy Centre at Newcastle. This facility has been established to research, develop and demonstrate the technology. It is the only multi-collector facility of its type in the southern hemisphere and has achieved international recognition.

At this centre, CSIRO has constructed a 500kW solar tower that can generate high temperature steam for power stations, or SolarGas. SolarGas is formed by using concentrated solar energy to convert natural gas into a synthetic gas. This gas can then be used to generate electricity in gas-fired power stations, or to produce liquid transport fuels via the process "gas to liquids". The technology combines two of Australia's largest and most sustainable energy resources (solar energy and natural gas), enables solar energy to be stored in chemical bonds, and thus for solar energy to be stored and transported. It would enable Australia to export its sunshine.

This tower technology concept will help to overcome one of the major hurdles of the technology at present – that of having to be built in large single units to provide economies of scale. The concept CSIRO is developing allows for smaller repeatable modules, so that large capacities can be built up by simply building multiple modules.

CSIRO is also developing lower temperature trough technology for distributed energy – small industry, shopping centres, etc. It can for example provide the energy needed to run a chiller or air conditioner, providing good load matching between solar radiation and the need for cooling.

CSIRO's aim is to rapidly develop a suite of solar thermal technologies that can make a large impact in a range of energy sectors.

Collaboration in the Australian innovation system

CSIRO is an active member of the international solar thermal community. Strong research ties are already in place with Germany, and have now grown to include new partnerships with Japan, China and South Korea through the AP6 program[27]. The two major solar thermal research organisations in Australia, CSIRO and ANU, have a strong relationship. It has long been recognised that a critical mass of expertise is essential for the industry. Collaboration has already occurred, and discussions held on future areas of mutual development. CSIRO is in partnership with a local SME, and in discussion with large multi-nationals. Given that solar thermal technology is made up of components from many industries (mirrored glass, mass component manufacturing, engineering services, etc) there is room for more widespread collaboration with Australian industry.

5. Solar Photovoltaics

Introduction

Photovoltaic cells (solar cells) are devices designed to convert sunlight directly into electricity. This section briefly summarises the technology development and manufacturing of photovoltaic systems that we are aware is currently underway in Australia. Solar technologies that convert sunlight into stored energy (chemical or heat) are not included.

Current status in Australia and globally

The market for photovoltaic (PV) solar technology is growing worldwide at a rapid pace driven by the fundamental demand for cost-effective renewable energy sources that do not contribute to greenhouse gases. The ongoing challenge of global warming is likely to see the high growth rate continue into the future. Growth is strongest where governments have implemented policies to encourage adoption of solar energy, eg. Germany, Japan, USA. In 2007 the student intake into Australia's only PV engineering degree programme (UNSW) increased from an average of 40 over previous years, to 70 students.

The current PV market, both in Australia and worldwide, is dominated by 'first-generation' technology, based on thick single- or multi-crystalline wafers of silicon. This market dominance is expected to continue for at least the next five years. Driven by a need to reduce the cost of photovoltaic electricity, a small, but growing percentage of the market is based on a number of different technologies, collectively referred to as 'second-generation' photovoltaics. Most forms of this technology are in the late stages of development and should benefit from a more favourable cost structure due to savings on material costs and also, in many cases, less capital-intensive manufacturing. One example of this technology with the potential to show significant market penetration in the near future is copper-indium-gallium-diselenide (CIGS) solar cells, for which a number of large manufacturing facilities are currently under construction internationally. It seems there is presently no development or manufacturing of CIGS technology underway in Australia.

The longer-term future of photovoltaic solar energy is currently in the research phase worldwide under banners such as 'third-generation' or 'next generation' photovoltaics. This range of technologies looks to further increase the cost-competitiveness of solar electricity either by increasing the energy conversion efficiency, or by further decreasing the manufacturing cost of the systems. These technologies can be split into three groups:

- advanced technologies based on silicon;
- photoelectrochemical cells with nanostructured electrodes, eg. the dye-sensitised solar cell (DSC); and
- solar cells made from organic (plastic) materials - organic photovoltaics (OPV).

CSIRO's research and capabilities

Photovoltaics research has been underway at CSIRO since late 2005 and focuses primarily on the development of OPV technologies based on organic (plastic) materials. The research is aimed at significantly reducing the cost of PV power generation by designing solar cells that can be manufactured cheaply from abundant materials, using less capital-intensive facilities. Room temperature fabrication processes will also result in less energy embodied in the solar cell. For these reasons organic materials will ultimately provide a more effective solution to the challenge of affordable, clean, solar electricity than inorganic materials such as silicon and CIGS.

CSIRO's Divisions of Molecular and Health Technologies (CMHT) and Energy Technology (CET) are working together to develop OPV technology. Chemists at CMHT are exploring new organic compounds and developing a fundamental understanding of the photophysical processes occurring in the new cells. They have developed a model that predicts the performance of OPV devices, based on the properties of the organic compounds used for the active layers. This model predicts that a conversion efficiency of >10% is achievable, which would overcome one of the barriers to commercial viability. Physicists at CET are addressing the other two barriers to large scale implementation of organic photovoltaics:

- research-scale fabrication methods are currently not capable of the high volumes necessary for manufacturing, and
- the durability of organic solar cells is still inadequate for practical applications.

CET has also begun the expansion of its National Solar Energy Centre to include a world-class PV characterisation facility, catering for the special requirements of OPV devices, whilst providing a base of expertise and infrastructure that will benefit the entire Australian PV research community. CSIRO photovoltaics projects also include research into improving the performance stability of the dye-sensitised solar cell (a semi-organic solar cell), which although a relatively mature technology, still lacks the durability it will need to penetrate the current PV market.

Collaboration in the Australian Innovation System

BP Solar Pty Ltd is the largest commercial PV manufacturer in Australia, producing 43.6 MWp of first-generation PV systems in 2006. It continues to develop its production process and is also researching improvements to its installation systems and procedures. Some of this research is conducted in partnership with Australian University groups.

Although manufacturing in Germany, CSG Solar's second-generation 'crystalline silicon on glass' PV technology was initially developed at the University of NSW. The company continues to improve the technology through research at its Sydney site.

Dyesol Limited, based in Queanbeyan, NSW, is the industrial research hub for the world's network of researchers into the dye-sensitised solar cell (DSC). Dyesol researches, develops and manufactures DSC components, including nanoparticulate pastes and dyes, as well as equipment specifically designed to research and manufacture DSCs. In May 2007 Dyesol announced that one of its main research partners, Queensland University of Technology, had been successful in securing a A$360k grant from the ARC for work on advanced DSC materials in project whose total value is A$1.4m.

Origin Energy Limited is in the late stages of commercialising the 'Sliver Cell' PV technology developed by the Australian National University. The technology promises crystalline silicon cell performance with significantly lower usage of silicon wafers, which are a key factor in the manufacturing cost. A 5 MWp pilot plant was constructed in Adelaide in 2004 and the company continues to refine its manufacturing process.

PV Solar Energy Pty Ltd has developed a PV roof tile which uses a low cost pluggable PV junction box and monocrystalline solar cell laminates. Installation options include active air flow in the roof space below the modules to keep them cool and to allow warm air circulation into the building during winter months.

Solar Systems Pty Ltd has developed and commercialised a PV tracking concentrator dish system for off-grid community power supplies and end of grid applications. Overall system efficiencies of 20% have been achieved. The systems were initially based on silicon cells, but testing of higher efficiency non-silicon devices is now underway.

As well as industry-led developments, there are a number of programs and centres dealing with photovoltaics at Australian universities (many of which partner with industry to develop photovoltaic technologies). These include:

- The Australian National University Centre for Sustainable Energy Systems - ARC Centre of Excellence for Solar Energy Systems;
- Monash University - ARC Centre of Excellence in Electromaterials Science;
- Murdoch University Research Institute for Sustainable Energy - 'ResLab' measurement facility;
- University of New South Wales - ARC Centre of Excellence for Silicon Photovoltaics and Photonics;
- University of Queensland - Centre for Photonics and Electronics;
- Queensland University of Technology Applied Nanotechnology Group (partnership with Dyesol Ltd);
- University of Melbourne School of Chemistry and Bio21 Institute;
- University of Newcastle Priority Research Centre for Organic Electronics; and
- University of Wollongong Intelligent Polymer Research Institute.

In 2005 the CRC for Polymers commenced a third period of funding under the Australian Government's CRC Program. Over the course of a three year project focusing on OPV, this CRC plans an investment of A$7m to fund research at CSIRO, ANSTO, University of Wollongong, University of New South Wales, and industry partner Ciba Specialty Chemicals.

In addition, a three ARC research centres involve coinvestment by ARC, universities and industry:

- University of Newcastle – Priority Research centre for Organic Electronics (University of Newcastle, ARC, Orica);
- University of Queensland – Centre for Photonics and Electronics (COPE) (UQ, NCRIS); and
- University of Wollongong – ARC Centre of Excellence for Electromaterials Science.

Australian university and CSIRO research groups are undertaking collaborative research with overseas universities and industrial partners through an A$2m DEST International Science Linkage Grant awarded to Federation Fellow Professor Andrew Holmes. The partners are: University of Melbourne, Monash University, University of Wollongong, University of Sydney, University of Newcastle, CSIRO, University of Queensland, Massey University, Imperial College of Science Technology & Medicine, Merck UK, Georgia Institute of Technology, Cornell University, A-Star IMRE (Singapore). Professor Holmes also leads a consortium awarded a grant of A$6m under the Victorian government energy technology innovation strategy – sustainable energy R&D to carry out research on OPV. The funding is matched by cash and in-kind contributions from the partners, which are CSIRO, Melbourne University, Monash University, BP Solar Pty Ltd, Merck UK, Securency Pty Ltd, and Bluescope Steel.

6. Wave and Tidal Energy

CSIRO currently does not conduct R&D in the areas of tidal or wave energy. There are isolated projects underway in Australia, in Wollongong and Western Australia, but CSIRO does not have links with these activities.

7. Geothermal energy

Introduction

Geothermal power involves harnessing heat from within the earth for electricity generation. A continuum of geothermal systems exists. New systems are discovered in different geological settings creating new opportunities. Terminology reflecting these ongoing changes varies among different researchers.

Current status in Australia and globally

Geothermal energy is well known to exist in immense quantities in Australia, albeit in forms that may be difficult to exploit using traditional geothermal technologies. Because of this difficulty, it is fair to say that the Australian geothermal industry is still mostly in its formative stages. Nevertheless, the current Australian investment market for geothermal companies appears to be quite buoyant.

The nomenclature below includes the temperature of the resource and the degree in which the water flow through the systems needs to be enhanced. The latter ranges from not at all (i.e. natural hydrothermal systems) to hot dry rock. Three basic kinds of geothermal energy systems are important.

High Temperature Hydrothermal/Volcanic Systems

These are the classical systems typified by the New Zealand, California, and Iceland style of geothermal electrical generation plants. They use natural water circulating near a hot volcanic chamber or similar body. They can reach 1.5 GW power production. This is the equivalent power production of a large nuclear or coal-fired power plant. Geysers are sometimes found with these systems. Examples range from the Wairakei system in North Island, New Zealand (160 MW) to The Geysers in California (1 GW sustained). There are limited opportunities for this style of geothermal systems in Australia. One exception may be the area near Mt. Gambier.

Low Temperature Hydrothermal Systems

In contrast to the above described system, low temperature hydrothermal systems are not necessarily linked to a cooling magmatic body. These systems are consequently much more common. They occur in natural sedimentary strata and/or naturally fractured rock containing hot water. An example is the Great Artesian Basin in South Australia and Queensland and, possibly, parts of New South Wales. These systems provide an opportunity for the direct use of geothermal heat without intermediate conversion into electricity.

Hot Dry Rock (HDR) and Enhanced Geothermal Systems (EGS)

"Hot Dry Rock" geothermal was pioneered in the 1970s and 1980s in Los Alamos in the USA, and in Cornwall in the UK by targeting the extraction of heat from dry granites. The granites produce heat from the natural radioactive decay of some contained minerals and the background heat flow. The exploitation system first injects then extracts water after it has been heated by contact with the rock.

The plumbing system between the injection and extraction wells must be established artificially by creating fractures in the rock. Local microseismic events are created by the fracturing process. A local source of water is necessary for extracting the heat and for cooling of the power plant. In Australia, these targets are commonly referred to as "Hot Rock" systems, after usage originating with the group at ANU.

The discovery of wet, deep, pre-existing permeable zones in projects that were thought to be targeting hot dry rock systems was a recent surprise to the Earth Sciences community. For example, Soultz Sous Forêts in the Rhine Graben officially started as a Hot Dry Rock prospect. After discovery of circulating water at depth, it is now the key example of an enhanced geothermal system (EGS). The nature of the heat source (either volcanic or background) is not constrained by the use of this terminology. The "enhanced" part of the name comes from engineering the natural water flow system through methods similar or identical to those used in Hot Dry Rock systems. For Australia the current exploration is in enhanced geothermal systems whereby the technology developed initially for hot dry rocks is used.

Traditionally, geothermal energy is exploited in near-surface high-temperature hydrothermal geological settings such as those near active volcanos, geysers, fumaroles and the like. Australia has relatively few such geological settings. To date, most Australian geothermal investment has centred on Hot Rock and EGS exploration settings – nearby deep igneous and metamorphic rocks containing their own natural mineralogical radiogenic heat sources. Direct use of geothermal heat has been deployed to date in a few niche opportunities such as large swimming pool heating systems. With direct use systems, electrical generation with its attendant inefficiencies is not required and hence lower temperature sources are economic.

In more mainstream fields, geothermal exploitation shares many fundamental technologies with petroleum engineering below ground, and steam fired generating stations above ground. CSIRO has activities, technologies, and capabilities in many allied R&D areas that are directly applicable to the development of this resource.

CSIRO research and capabilities

Geothermal energy related activities are based widely within CSIRO across research Divisions of Exploration and Mining, Petroleum, Land and Water, Energy Technology, Manufacturing and Materials Technology, Industrial Physics, and Textile and Fibre Technology. Geothermal efforts to date have involved both contracted research with Australian geothermal companies as well as development of other technologies applicable in wider domains and ranges across a number of areas, relating to the processes of geothermal energy extraction as well as the physics of heat exchange.

CSIRO researchers are investigating the process of extraction of geothermal energy in terms of mechanical technologies, the use of fluids and hydraulic fracturing. Work is also underway in targeting potential reservoirs including by use of GIS systems and exploration geophysics. This research is performed in partnerships with Australian universities and the University of Minnesota.

CSIRO is developing an Organic Rankin Cycle (ORC) engine, targeted for energy conversion from low and medium temperature thermal energy to electricity. Potential applications include solar thermal, geothermal and waste heat recovery, and commercialisation is anticipated to begin in 2007/08. Additional technologies under development include combined cooling, heating, and power using geothermal energy where the energy source temperature is relatively low and generally below 200 °C and Stirling engines.

Collaboration in the Australian innovation system

Because geothermal is a relatively new industry, Australian research capacity in this field has been mostly split between the University sector (Monash, Adelaide, and formerly at ANU), State and Commonwealth geoscientific agencies, and CSIRO. Worldwide, research is similarly attuned to the local conditions; the EU driving EGS research for the Rhinegraben, with Japan, the USA, Iceland and New Zealand leading high temperature efforts, and with direct-use and geothermal heat pumps being deployed widely for space heating in the colder climates. The fact that low temperature hydrothermal resources are available at relatively shallow depths underneath some Australian population centres (eg the Perth Basin) may well lead to a world-leading role for Australian R&D in that arena.

8. Wind Energy

Introduction

Wind power is the conversion of wind energy into more useful forms, usually electricity, using wind turbines. At the end of 2006, worldwide capacity of wind-powered generators was 74GW. Although it currently produces less than 1% of world-wide electricity use, it accounts for approximately 20% of electricity use in Denmark, 9% in Spain, and 7% in Germany. Globally, wind power generation more than quadrupled between 2000 and 2006.

Most modern wind power is generated in the form of electricity by converting the rotation of turbine blades into electrical current by means of an electrical generator. Wind power is used in large scale wind farms for national electrical grids as well as in small individual turbines for providing electricity to rural residences or grid-isolated locations.

Wind energy is plentiful, renewable, widely distributed, and reduces toxic atmospheric and greenhouse gas emissions if used to replace fossil-fuel-derived electricity.

Current status in Australia and globally

Wind energy is a significant player in the renewable energy field. The success of wind power in helping fulfil the MRET has demonstrated that the Australian wind energy industry can respond to the need for zero emission energy generation in Australia. Overseas experience has shown that wind energy generation is rightly considered an off-the-shelf technology, able to be deployed in significant quantities, with short lead-times and with steadily improving economics. The main challenges for Australia are not in the turbine hardware systems but in the satisfactory location of developments and the integration of significant quantities of wind energy generation into to the electricity grid infrastructure and electricity market systems.

In this context high quality and high resolution wind resource mapping can lead to good planning and potential prequalification systems for areas of development. The natural wind energy intermittency can be significantly mitigated by good quality wind production forecasting and the use of intelligent electricity storage systems.

The need for a wind forecasting system was recognised in the Australian Government's *Energy White Paper* of 2004[28] and the funding of the Australian Wind Energy Forecasting System (AWEFS) under the auspices of National Electricity Market Management Company (NEMMCO). Countries such as Denmark and Germany have shown that accurate forecasting of wind energy production can allow complementary generation sources to be scheduled so that extra spinning reserve requirements (and hence costs) can be minimised.

CSIRO is an active participant as a member of the AWEFS research reference group and the NEMMCO wind forecasting expert reference panel and will be involved in the further development of the NEMMCO operational system as it is adapted and improved for Australian conditions. CSIRO has undertaken studies for the Australian Greenhouse Office (AGO) including examining the impact of extreme events on wind energy generation levels in the national grid.

Australian expertise in this area has been recognised by an invitation to join an EU Framework 7 research consortium working on forecasting wind generation in extreme weather conditions (SafeWind).

Globally the wind industry has recognised grid–integration as one of the key constraints on the continued growth of wind energy as a major player in the power industry. Problems lie both in the electrical characteristics of wind farms and in the intermittency of energy production. While it is possible to take measures to ensure wind farms comply with network requirements, it is more difficult to deal with the inherent variability in energy generation. This variability covers a broad range of scales from seconds to hours and beyond. NEMMCO has identified that short–term variability (sub one–hour) can be quite substantial under some conditions where sizable wind generating facilities are present. This creates significant problems of voltage support and frequency control, as well as causing excessive peaking on transmission lines (thus reducing carrying capacity) and increasing demand for high ramp–rate backup systems. This is particularly important where substantial wind generation is present at the extremities of the grid or on relatively small capacity power lines, as is often the case.

CSIRO research and capabilities

CSIRO has been active in the area of wind energy research for more than 17 years and currently has about 12 people working in this area. CSIRO's primary role is providing R&D to remove impediments to the successful deployment of wind energy in Australia, including a very active industry support role in the key areas of wind resource assessment, wind generation forecasting and storage systems for renewable energy. This work is conducted under the auspices of the Energy Transformed Flagship and the Marine and Atmospheric Research Division.

CSIRO has developed and commercialised systems to locate and quantify wind resources in Australia, contributing significantly to the early development of the industry. The technologies have been successfully deployed in Australia and overseas by CSIRO's spin-off company, Windlab Systems (www.windlabsystems.com). There were two key findings of this work:

- High resolution wind resource information must always be combined with other factors such as proximity to power line infrastructure, land use type and amenity level to form a complete planning system. An example of this approach was the *Victorian Wind Atlas* [29]. This should enable a prequalification system to be developed to prevent the level of effort wasted in preparing development applications which have little chance of success.
- The economics of wind energy generation is directly related to the level of wind resource. If the cost of generation improves or the level of support for the industry increases then the amount of wind resource needed to break-even is lower. The amount of land available with viable wind resource increases exponentially as the break-even point lowers. Our studies showed that, for example, in the Great Divide area of NSW there was only 130 km^2 available with a wind speed exceeding an annual average wind speed $8ms^{-1}$, this being the approximate economic break-even point for the MRET scheme. If the break-even point implied an annual average wind speed of $7ms^{-1}$ then 20 times the land area would be available for consideration.

The intermittency of wind energy generation is well recognised. This occurs at a wide range of timescales from the obvious longer periods coinciding with the passage of weather systems to shorter timescales coinciding with wind gustiness. In the first instance the variability in the wind may not matter if wind energy only represents a small fraction of generation but problems arise when wind is a significant fraction, such as has already occurred in South Australia. Knowing when, where and how much wind energy will be delivered is key to being able to arrange for the smooth integration with other energy sources. Hence a high quality wind energy production forecasting system is a major requirement to the deployment of wind power.

Through the Energy Transformed National Research Flagship, CSIRO is demonstrating renewable energy storage systems which provide a solution to the short term wind variability problem. They provide smoothing of the output of wind farms as well as conventional voltage stabilisation and frequency control. The benefits include:

- Significant reduction in short-term variability from wind farm (output from a typical large wind farm will see a reduction by 70% in ramp rates which exceed NEMMCO[30] error limits);
- smoother voltage and power delivery;
- increased carrying wind power capacity of local transmission lines;
- increased wind penetration on grid;
- increased flexibility in siting wind farms; and
- possible combination with provision of compulsory ancillary services (ride through, voltage support and frequency control).

These systems are equally applicable to remote area power supply systems which may include a combination of power sources including wind, solar and diesel.

Collaboration in the Australian innovation system

Australian wind energy research projects are currently being conducted by only three providers - the Centre for Energy and Environmental markets, the Bureau of Meteorology Research Centre and CSIRO. The Australian Greenhouse Office (AGO) has committed to fund the development and implementation of an Australian Wind Energy Forecasting System (AWEFS) involving these three research providers in collaboration, over a four-year period. NEMMCO has agreed to implement and operate the AWEFS and complete the project.

9. Hydrogen energy

Introduction

Hydrogen energy can provide a mechanism for utilising fossil fuels by reducing emissions. It can act as energy storage and a carrier for renewable energy sources.

Current status in Australia and globally

Hydrogen is just entering the energy mix in a number of countries, mainly via demonstration projects. Recent investment in hydrogen R&D internationally is focussed on development of a hydrogen economy, although it is recognised that this is a long term proposition. Currently hydrogen energy is not a cost effective technology, although it is expected that costs will fall with new technologies.

The National Hydrogen Study[31] identifies common themes globally in activity related to hydrogen:

- Improving efficiency and reducing cost of fuel cells;
- Reducing the cost of hydrogen production;
- Pursuing carbon sequestration opportunities;
- Demonstration project funding;
- Work on uniform codes and standards; and
- Forming public/private partnerships.

Australian research recognises that improved hydrogen storage densities in a range of solid-state storage materials are essential for mobile (principally automotive) applications and are also required for load-levelling in stationary applications. It is generally accepted that breakthroughs, rather than incremental advances, are required in order to meet the US Department of Environment targets, for onboard hydrogen storage, designed to promote scientific research in the area of hydrogen storage.

Current R&D also aims to improve the efficiency and cost-effectiveness of hydrogen energy production. Approximately 96% of hydrogen energy produced world-wide is currently produced by steam reforming of hydrocarbon feedstock. This is likely to remain the most cost-effective method for producing hydrogen energy in the near future. While the technology is reasonably mature, improvements in efficiency are possible if catalysts can be developed which will allow operation at lower temperatures.

Much of the remaining hydrogen energy produced today is via electrolysis of water. Electrolysis, combined with renewable electricity from, for example, wind turbines, offers a route for hydrogen energy production free of CO_2 emissions.

CSIRO's research and capabilities

CSIRO is supporting research on hydrogen production, storage and utilisation through the National Hydrogen Materials Alliance (NHMA) Collaboration Agreement (a Flagship Collaboration Research Fund).

Collaboration in the Australian innovation system

The NHMA comprises researchers from 11 Australian universities, together with ANSTO and CSIRO. CSIRO funding for the research program, which commenced operation in September 2006, totals A$3 m over the initial three-year lifetime of the program. The research program of the NHMA addresses production, utilisation and storage.

A current project examines issues involved in integrating electrolysis systems with renewable electricity sources and fuel cells to produce efficient integrated storage/supply systems. Other work aims to produce hydrogen from water in an electrochemical cell, using sunlight as the energy source, without any need for an external electricity supply. As such, it promises a cost-effective source of hydrogen free of CO_2 emissions.

An efficiency of approximately 10% is required for commercial viability. The best systems under development have efficiencies well below this target. NHMA research work aims to develop improved photo-catalysts in order to raise the efficiency towards the 10% goal.

Finally, a NHMA project to develop improved catalysts for use in solid-oxide fuel cells (SOFC) is underway. Efficient, reliable fuel cells are vital for the development of a hydrogen economy, and SOFC are a promising technology for stationary applications. The work on SOFC in the NHMA complements work on membrane fuel cells and electrolysers in CSIRO.

Research supported through the NHMA is an extension of existing research programs in the collaborating institutions. It provides a mechanism for bringing together researchers from different institutions in targeted research programs which are complementary to objectives in CSIRO.

10. Conclusion

In Australia, the application of renewable energy has not achieved the levels reached in some other parts of the world. This is because Australia has an international advantage in our abundant reserves of fossil fuels consisting mainly of coal and gas. The well-managed exploitation of these resources has given us one of the most cost effective energy supply sectors in the world. This has limited the incentives for the widespread take up of renewable energy technologies, as these technologies under present energy pricing conditions, are more expensive than renewable energy options.

However, as Australia confronts the need to operate in a lower carbon emissions future, the role of renewable energy will come increasingly into focus. This is especially the case as it is now certain that there will be a price of carbon emissions in the short term, most likely through a carbon trading scheme. Depending on the price of carbon emissions over time, the gap between renewable and fossil energy prices will narrow and this will make some renewable energy technologies more cost competitive in our future energy mix.

While wind energy and biofuels currently appear to have the best short to medium term potential for addressing the need for renewable energy generation in Australia, other less developed sectors such as third generation solar photovoltaics and geothermal energy, based on hot, fractured rocks, have potential to contribute more in the longer term, with hydrogen energy so early in development that an assessment of the real potential is difficult.

In all cases, R&D to address barriers to uptake such as cost effectiveness and integration with the electricity grid is ongoing in the Australian innovation system and will ultimately support the required development of a secure, cost-effective energy supply for Australia's future.

Endnotes

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2 http://www.greenhouse.gov.au/markets/mret/

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13 Biofuels in Australia – issues and prospects (2007) Rural Industries R&D Corporation http://www.rirdc.gov.au/reports/EFM/07-071.pdf

14 Ensis is CSIRO's entity for its core forestry, wood and paper (and allied industries and related government agencies) sector research, science and technology delivery. It is a 50:50 unincorporated joint venture between CSIRO and a New Zealand forest research group called Scion

15 http://www.bioenergyaustralia.org/about.html

16 http://www.a3p.asn.au/keyissues/bioenergy.html

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18 Rutovitz, J. and Passey, R. (2004) N*SW Bioenergy Handbook.* Mark Ellis & Associates, Sydney, Australia.

19 A joint R&D support program funded by the Rural Industries R&D Corporation, Forest and Wood Products R&D Corporation and Land and Water Australia – see http://www.rirdc.gov.au/programs/aft.html

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21 http://www.fwprdc.org.au/content/pdfs/new%20pdfs/Forests,Wood&CarbonBalance.pdf

22 http://www.bcse.org.au/default.asp?id=105&articleid=10

23 http://www.greenhouse.gov.au/renewable/recp/biomass/one.html

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27 AP6, The Asia-Pacific Partnership on Clean Development and Climate is an innovative new effort to accelerate the development and deployment of clean energy technologies. See http://www.asiapacificpartnership.org/

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Appendix 1 Terms of Reference

The House of Representatives Standing Committee on Industry and Resources shall inquire into and report on the development of the non-fossil fuel energy industry in Australia.

The Committee shall undertake a comparative study of the following renewable energy sectors: solar, wave, tidal, geothermal, wind, bioenergy and hydrogen. The case study will examine the relative state of development of these sectors and their prospects for economically viable electricity generation, storage and transmission.

Appendix 2 NHMA projects

Project #	Title	Collaborators
1	Hydrogen storage in materials based on lithium	Griffith University. Curtin University of Technology
2	Hydrogen storage in materials based on magnesium	University of Queensland Curtin University of Technology Griffith University Monash University RMIT University of NSW University of Wollongong
3	Hydrogen storage in carbons	Curtin University of Technology Griffith University Monash University RMIT University of NSW University of Queensland University of Wollongong
4	Hydrogen storage in porous materials	Curtin University of Technology Griffith University University of NSW
5	Development of new catalyst materials for hydrogen generation from hydrocarbon fuels	University of Queensland University of Newcastle University of NSW
6	Development of electrolysis systems	RMIT University of Queensland
7	Development of photocatalytic materials for hydrogen production by water splitting	Queensland University of Technology University of Queensland University of NSW University of Sydney ANSTO
8	Development of materials for advanced hydrogen fuel cells	University of Queensland ANU