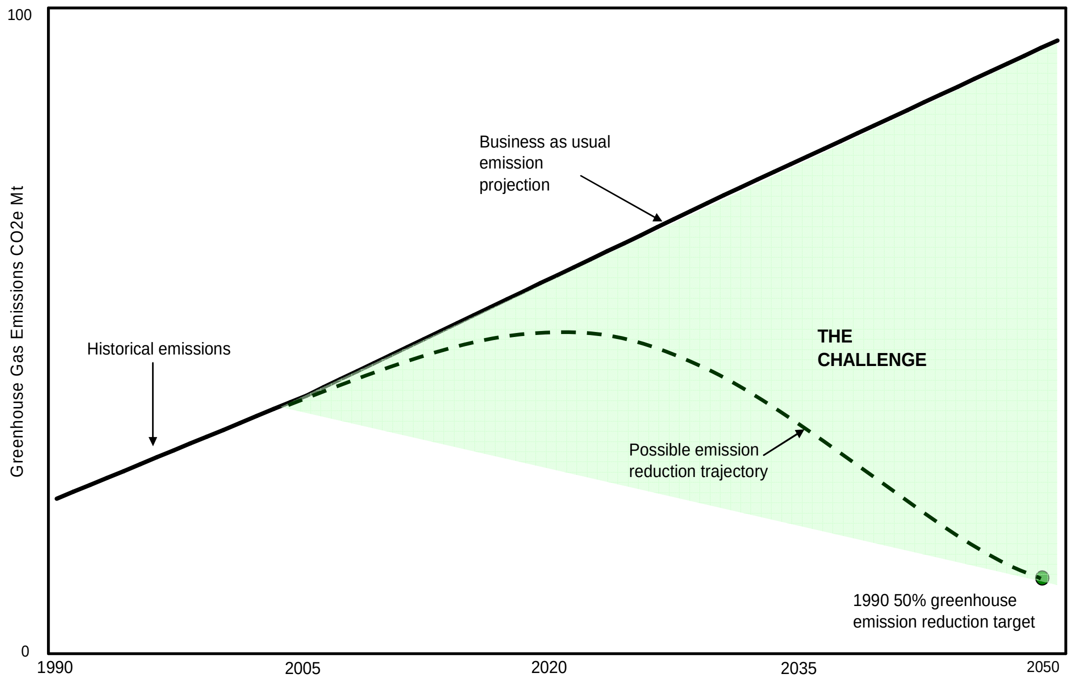
CONFIDENTIAL

TECHNOLOGY OUTLOOK FOR STATIONARY ENERGY IN WESTERN AUSTRALIA



Source: Greenhouse and Energy Taskforce (WA), Chairman, Dr R Green (2006)

a report prepared for and on behalf of the Western Australian Greenhouse and Energy Taskforce
by
Dr Joseph Patroni, 13 December, 2006.

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KEY MESSAGES

1. Currently, with 1.7% of the Earth's land area and 0.03% of world's population, producing 40 $MtCO_2$, or 0.16% of global CO_2 emissions, annually from stationary energy, Western Australia is positioned for a measured response to the global challenge in climate change.

2. Whilst awaiting a unified global approach, accelerated technological innovation is an internationally accepted way of tackling climate change and positioning for economic opportunity. In this context, the recent Stern report advocates a doubling of research funding and a five-fold increase in incentives for technology deployment.

3. Western Australia's direct public investment in energy-related research currently averages at about $5 million annually and together with indirect investment, historically represents about 10% of total state investment in research over the past 15 years. Publicly supported research capability covers a broad range of expertise, from organic renewables, to deep sea natural gas recovery, but is generally sub-critical on an internationally competitive scale, growing at about 5 new researchers per year.

4. Subject to availability of relevant infrastructure, critically-scaled research activity is being developed in targeted areas relevant to the private sector as and when required.

5. The most significant Commonwealth investments in recent explorative research through the Australian Research Council were in solar photovoltaics, followed by intelligent transport systems, hydrogen and fuel cells.

6. Commonwealth projections for the deployment of future energy technology demonstration initiatives, highlight "energy efficiency" as the most prominent area for investment.

7. Western Australia's recent stationary energy technology deployment initiatives include the Western Power/Alinta/Griffin/Energy wind farms; Verve Energy/CSIRO's biofuel gasification pilot, Renewable Energy Holding's wave energy pilot; Cool Energy Ltd's trial of cryogenic CO_2 separation; and Gorgon's geosequestration plans.

8. Combined cycle natural gas-fired energy production delivers 42% efficiency and remains competitive at $0.02 – 0.03 per kWh (in 2005) but vulnerable to future gas prices now at 60-80% of generation costs.

9. Off-grid PV capacity in Western Australia remains relatively small with a 31kW installation in Hamersley, in 2005, and a 32kW installation in Laverton, in 2006.

10. Solar thermal energy can be applied to produce versatile syngas from methane incorporating 26% of the solar energy into the product gas.

11. Given its potential for base-load power, it is surprising that there appear to be no geothermal energy developments underway, as yet, in Western Australia and a detailed evaluation of any impediments is suggested.

12. Grid-linked wind power presents as a mature technology with further technological gains expected to feed better cost outcomes into the future from the current $0.04-0.05/kWh (in 2005) best practice.

13. Higher thermal efficiencies are the most practical way of reducing CO_2 emission for the coal industry.

14. The WMO/UNEP notes that for large stationary energy plants, carbon capture and storage within geological or ocean storage systems will require an additional 10-40 per cent of the energy solely for the capture and compression operations; adding $0.01-0.07/kWh to electricity costs.

15. Biomass production options in Western Australia conceptually benefit from access to a vast land mass, increasing CO_2 concentrations and high solar fluxes, but are limited by seasonal intermittency, potential displacement of food production, diminishing precipitation and declining access to suitable water resources.

16. Water Corporation and Organic Resources Technology Ltd currently generate about 6GWh from sewage waste biomass.

17. In 2004-05, the electricity generated on the South West Interconnected System by Western Power was 28TWh distributed over a network covering some 322,000 sq km to 838,997 customers and with a line loss of almost 2TWh.

18. Technologies associated with large-scale energy storage are important components in smoothing the intermittency experienced in power systems from most renewable energy sources. Other than pumped storage hydropower, there are, as yet, no significant technology deployments in Australia for energy storage.

19. Thermochemical storage of solar energy to convert methane to the more versatile and higher calorific-value syngas and downstream products, is a relevant technology in the medium-term, particularly, for Western Australia with its access to abundant solar energy and natural gas resources.

20. At the frontier of public policy, the many complexities and uncertainties presented by climate change over centennial timescales require an iterative approach to technology policy development. This allows regular evaluation of risk and changes in the energy cost base in progressing towards the long term goal for an emission free energy economy.

21. In view of the State's diverse geographic characteristics, expanding energy needs and important strategic interests, a dedicated energy technology policy development and implementation role is suggested. Such a role would initially focus on whole-of government initiatives, such as the Energy Technology Innovation Strategy foreshadowed by the former Minister in 2005, and would benefit from a review of the relevant legislative base.

22. Future improvements in gas separation, particularly within the next 30 years, will be at the core of many future clean energy developments and the higher efficiencies necessary for emissions abatement, and ultimately, the goal of zero emissions.

Recommendations:

1. **In partnership with industry and academe, and as part of an Energy Technology Innovation Strategy, scope and plan the science infrastructure needs, including human capital needs, relevant to the development of world-scale research activity to 2015 (p.13);**

2. **In partnership with industry, identify suitable sites for the early deployment of demonstration plants for the following processes/technologies: geothermal, geosequestration, wave power, photovoltaics, efficient coal conversion, and biofuels from sewage and cellulosic wastes (p.18);**

3. **Review any regulatory or technical impediments to the development of geothermal power in Western Australia (p.25);**

4. **In light of the modelled impacts of climate change relevant to Western Australia and the potential for biosequestration through offsets, undertake a review of the State's carbon storage capacity within its terrestrial flora to 2050 (p.32);**

5. **Promote and support the development of technologies for the conversion of methane from natural gas into higher value applications such as methanol and syngas with the incorporation of renewable energy (p.34); and**

6. **As part of an Energy Technology Innovation Strategy, prioritise support over 10 years for research and development into nanotechnology initiatives applicable to the efficient separation of gases (p.41).**

INTRODUCTION

In July 2005, the then Minister for Science and Innovation established the Western Australian Greenhouse and Energy Taskforce. This report was requested by the Taskforce in September 2006. The report is intended to support the Taskforce in formulating its response to the Terms of Reference, and set the foundation for an Energy Technology Innovation Strategy, requested by the then Minister. The style of the report is designed to inform the process of public policy formulation, by drawing, in condensed terms only, from verifiable data and key developments in technology and research activities relevant to Western Australia.

- Interfacing frontiers for science, economics and public policy

The imperative for considered global action to mitigate climate change was identified in the 1980s and clearly articulated in the 1987 report of the World Commission on Environment and Development entitled: "Our Common Future".[1] It is now increasingly evident that, to the extent that linear increases in CO_2 concentrations in the atmosphere observed over the past 200 years will result in global warming, nature's laws and dynamics dictate that flow-on environmental and socio-economic impacts will be disproportionate and non-linear. This serves to embed immeasurable uncertainty into conventional modelling scenarios, thereby limiting their predictive capacity.

For instance, despite a 30% increase in atmospheric CO_2 concentration, the Earth's surface temperature has increased by 0.5-0.6^{o}C over the past 100 years, somewhat less than models had predicted according to NASA.[2] Noticeably, however, much of this increase has occurred in the past few decades.[3] Latest scientific reports suggest that surface temperature has risen by 0.2 ^{o}C per decade in the past 30 years.[4] There is now broad consensus that climate change arising from anthropogenic activity is real after some 30 years of scientific endeavour, despite some variation in reports. In considering what action is to be taken, there is the realisation that we are at the frontiers of science, economics and, consequently, policy-making.

In 2006, it remains that the scale and scope of humanity's global response to climate change awaits leadership and, ideally, a unified and concerted approach. Currently, with 1.7% of the Earth's land area and 0.03% of world's

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1 The World Commission on the Environment *Our Common Future* (New York : Oxford University Press, 1987)
2 Herring, David, Ocean & Climate", NASA, *Earth Observatory*, <http://earthobservatory.nasa.gov/Library/OceanClimate/> (December 2006)
3 USA. National Research Council, Committee on Surface Temperature Reconstructions for the Last 2,000 Years *Surface temperature reconstructions for the last 2,000 years* (Washington, DC : The National Academies Press, 2001), p 3-4 <http://fermat.nap.edu/books/0309102251/html/3.html> (December 2006)
4 Hansen J, Sato M, Ruedy R, Lo K, Lea D W, and Medina-Elizade M, "Global temperature change" *Proc. Natl. Acad. Sci.,* 2006, 103, 14,288–14,293 <http://www.pnas.org/cgi/content/full/103/39/14288> (December 2006).

population producing 40 $MtCO_2$, or 0.16% of global CO_2 emissions, annually from stationary energy, Western Australia is positioned for a measured response to the global challenge in climate change. In the circumstances, the State would be encouraged to secure its economic position mindful of its dependency on the global commons, air and ocean.

Most importantly, anticipating revolutionary changes to socio-economic structure, arising from climate change, should be viewed locally as an opportunity for improved competitiveness through timely innovation and adaptation. This will particularly require understanding and innovative management, by government, of secure outcomes and the fundamental interrelationships between energy, water and economic infrastructure.

Whilst awaiting a unified global approach, accelerated technological innovation is now an internationally accepted way of tackling climate change and positioning for economic opportunity. In this context, the recent Stern report advocates a doubling of research funding and a five-fold increase in incentives for technology deployment.[5]

At a local level, technological solutions are anticipated within this report that support regional development and sustainable socio-economic function with low-level risk of failure. The report endeavours to identify, from the many possibilities, only the most relevant and applicable processes for stationary energy production in Western Australia, to 2030 and beyond. Each process is considered in light of the diverse geographical characteristics and substantial energy resources available. The report further interpolates suitable research, development and deployment of advanced technologies intended to secure future competitiveness outcomes. In keeping with a measured approach, proposed research activity is scaled to match the State's resources, capabilities and dependencies.

To facilitate meaningful technical comparisons of energy data, uniform units of measure and normalised costs in Australian currency are used where possible.

- A snapshot of national research and development activity

Exploratory research

On 1 June 2006, the Council of Australian Government's (COAG) Climate Change Group reported on a plan for collaborative action on climate change. The report included a national perspective of gaps in support for low emission technologies (largely focussed on stationary energy) that relate to comparative advantage and could be adopted for use in the Australian

[5] United Kingdom. Her Majesty's Treasury *Stern Review: The Economics of Climate Change* (Cambridge : Cambridge University Press, 2006) (30 October 2006) < http://www.hm-treasury.gov.uk/media/9A3/57/Ch_16_accelerating_technological_innovation.pdf> p 347 (December 2006).

context.[6] Whilst the report acknowledges the paucity of relevant real-time information, it includes a summary of investment in energy technology research by the Australian Research Council (ARC) in 2005, as indicative of the national research activity and investment at the explorative, high risk, level (Figure 1).

The summary shows that the most significant Commonwealth investments in recent explorative research were in solar photovoltaics, followed by intelligent transport systems, hydrogen and fuel cells.

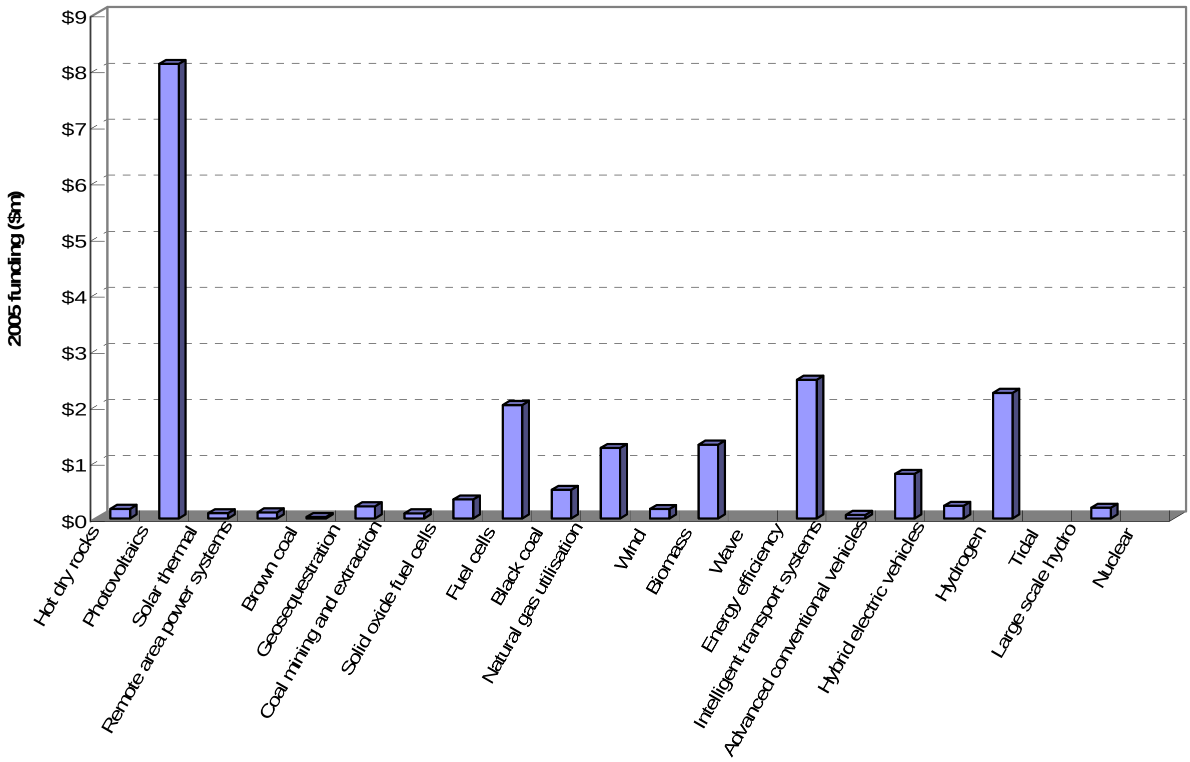

Figure 1. ARC funding for energy technology research in 2005
Source: COAG Climate Change Group Report, 1 June 2006

Commercially oriented research

At a more applied level, Cooperative Research Centres (CRCs) remain a means, proven over 15 years, by which the Commonwealth formulates a critical mass of resources to deliver commercially driven research outcomes. These centres typically combine industry, academe, CSIRO, government and other relevant resources in nationally competitive, corporatised research programs, undertaken over a seven year period. Notwithstanding this successful research model, it is recognised that the current program criteria requiring substantial industry participants in CRCs, not just industry investment *per se*, constrains the prospect of new technologies being

[6] Australia. Council of Australian Governments (COAG) *First Report of the COAG Climate Change Group, Energy Technology Gaps Working Group* (Canberra : COAG, 2006)

developed outside of the traditional industry sectors. This constraint particularly limits the fledgling renewable energy sector.

Of the 71 CRCs developed since 1990, the following six CRCs have current research programs relevant to energy and emissions:

- CRC for Clean Power from Lignite (CRC Lignite)
- CRC for Greenhouse Gas Technologies (CO2CRC)
- CRC for Coal in Sustainable Development (CCSD)
- the CRC for Advanced Automotive Technology (AutoCRC)
- CRC Mining
- the CRC for Construction Innovation (CRCCI)

These CRCs currently represent the national research focus to 2012 and undertake research into clean coal, CO_2 management, mining efficiency and automotive emissions (Figure 2).

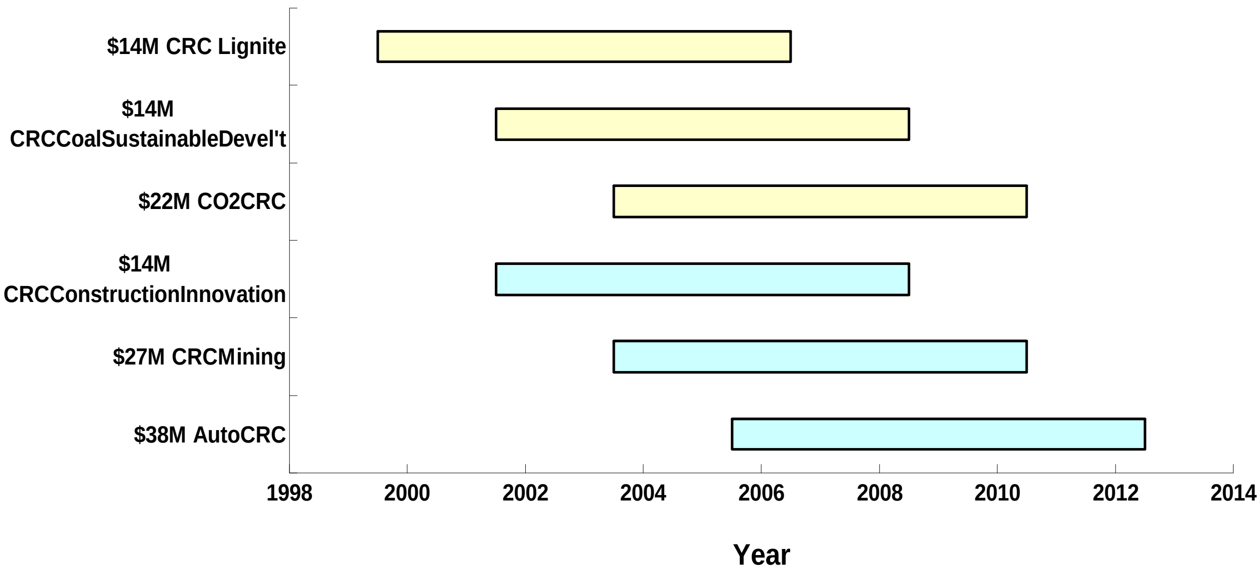

Figure 2. Commonwealth investment and timescale for energy-relevant CRCs
Source: adapted from COAG Climate Change Group Report, 1 June 2006

From the $2.1 billion invested by the Commonwealth in CRCs since 1990, $129 million, or some 6%, has been invested in CRCs relevant to energy and Greenhouse Gas (GHG) emissions. Only about $50 million, or 2%, has been invested in activities relevant to stationary energy from the CRC program. Successful applicants to the next round of the program, to be announced in December 2006, will collectively attract a further investment by the Commonwealth of over $400 million.

THE WESTERN AUSTRALIAN RESEARCH AND TECHNOLOGY LANDSCAPE IN 2006

- Energy research capability, infrastructure and investment

A competitive base in energy research

Since 1991, the Western Australian State Government has invested systematically in the development of local research capability and infrastructure primarily through the Centres of Excellence (COEs) program, which also supports local nodes of the Commonwealth's CRC program. This program particularly nurtures the local development of diverse research capability through self-selection of those competitive applications which align to economically relevant and sustainable research activities. COEs typically formulate industry, academe, government and other resources into collaborative research programs delivering sustainable, embryo-scaled models of CRCs. Many local COEs subsequently develop or link into national CRCs.

Of the $34 million invested by the State through the program in the 15 years to February 2006, $3.8 million, or some 11%, was invested in the following five local centres relevant to energy research:

- Western Australian Centre for Petroleum Geology;[7]
- Australian CRC for Renewable Energy;[8]
- Western Australian Petroleum Research Centre (WAPRC);[9]
- Centre for Organic Waste Management;[10] and
- CRC Coal in Sustainable Development[11]

Analysis shows that, collectively, the centres attracted $16 million of additional cash investment including the employment of 24 new researchers and $3.7 million of new infrastructure.

On a self-selected, competitive basis, over the past 15 years, the indicative investment or activity in energy and emissions research in Western Australia was at the level of about 10% of overall research activity, as evident in the COE program outcome. This compares favourably on a similar basis to the national position as reflected in the CRC outcome with its corresponding level of investment/activity of 6%. However, the COE investment in research relevant to stationary energy is estimated at less than 2% and about the same as the Commonwealth's level of investment through CRCs.

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[7] Formerly with Curtin University Research and Development from 1998-2006.
[8] Former ACRE capability now with the Research Institute for Sustainable Energy, Murdoch University.
Research Institute for Sustainable Energy <http://www.rise.org.au> (December 2006).
[9] Now the ARC Centre for Offshore Foundation Systems (COFS).
Centre for Offshore Foundation Systems <http://www.cofs.uwa.edu.au/> (December 2006).
[10] *Centre for Organic Waste Management* <http://cowm.murdoch.edu.au/> (December 2006).
[11] *CRC Coal in Sustainable Development*) <http://www.ccsd.biz/> (December 2006).

Targeted public investment in MERIWA and WA-ERA

Having broadened the research base, in 2004, the State recognised a need for significant investment in targeted public research initiatives. The State's major investment in the energy sector was committed through the WA-Energy Research Alliance (WA-ERA), established in 2004, and which currently absorbs about 80% of public investment in energy research locally. WA-ERA is an alliance between universities, CSIRO and industry. It was established with an investment of $20 million by the State over 5 years to support technological development in the local natural gas and petroleum areas.[12] WA-ERA's capability stemmed from its roots within the WAPRC COE and, in its first two years, grew with the appointment of 6 new researchers.

Further low-level public investment on targeted research projects has been provided through the Sustainable Energy Development Office (SEDO) and the Minerals and Energy Research Institute of WA (MERIWA), established under the *Minerals and Energy Research Act* 1987. In 1995, management but not funding of MERIWA's energy-related program, was transferred to the Office of Energy, and then onto SEDO, in 2001.

Annually, SEDO allocates about $0.2 million towards technology development across 6-10 projects, leveraging predominantly in-kind support. According to MERIWA's analysis of its past 45 research projects, 8 projects related to hydrocarbons, with some 50% of the investment in research activity focussed on emerging technologies relevant to engineering, mining and geoscience. MERIWA operates with an annual budget of $0.65 million and over the past two years, leveraged external investment in research of about $3 for every $1 of public investment.

Leveraged investment into public research

Leverage ratios serve as a useful indicator of research competitiveness, investment attraction capacity, the commercial relevance of research activity and policy focus. According to the latest certified performance indicators from the Department of the Premier and Cabinet, whilst the total investment quantum for research in Western Australia steadily increased ($1.1 billion in 2002-03), the rolling average leverage ratio peaked in 2003-04 and somewhat dramatically halved in one year to 2004-05 (Figures 3,4).[13]

Correspondingly, a substantial 57% increase to $1.7 billion in total research and development investment for the 2004-2005 period, as recently reported by the Australian Bureau of Statistics (ABS), suggests that the dramatic decline in leveraged research into public initiatives cannot be explained by the underlying trends in investment or competitiveness variables, but is more symptomatic of an altered policy focus. This may impact on future research capability in the public sector.

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[12] *Western Australian Energy Research Alliance* <http://www.waera.com.au> (December 2006).

[13] Western Australia. Department of the Premier and Cabinet *Certification of Performance Indicators: Annual Report – 2004/2005* (Perth : Auditor General, 2005) <http://www.dpc.wa.gov.au/documents/annual_report/2005/performanceIndicators.pdf> p 103-104 (December 2006).

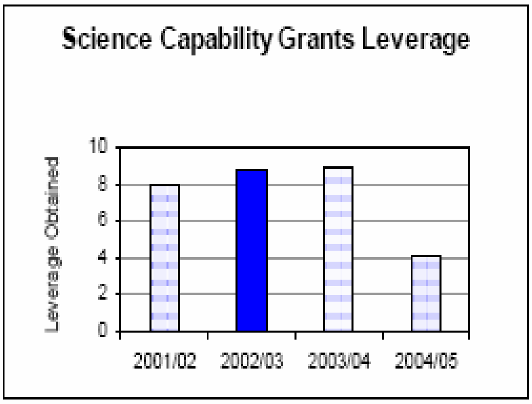

Figure 3. Rolling average leverage ratio for public investment in major research activity in Western Australia 2001-2005
Source: 2004-05 Annual Report, Department of Premier and Cabinet (WA)

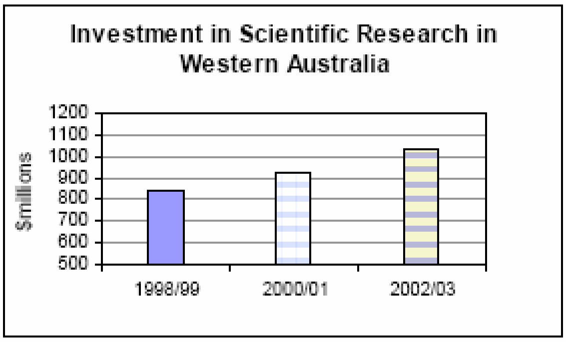

Figure 4. Total direct investment in scientific research 1998-2005
Source: 2004-05 Annual Report, Department of Premier and Cabinet (WA)

NOTE: 2004-05 data from ABS released on 11 October 2006 shows a 57% increase in investment from the previous year to $1,740 million.

Science policy outcomes

In summary, Western Australia's direct public investment in energy-related research currently averages at about $5 million annually, and together with indirect investment, historically represents about 10% of total state investment in research. Publicly supported research capability covers a broad range of expertise, from organic renewables, to deep sea natural gas recovery, but is generally sub-critical on an internationally competitive scale, growing at about 5 new researchers per year. In general, public research capability is supported by limited, although modern, science infrastructure and allied capabilities, but appears now to be declining in its ability to leverage direct investment into public initiatives from non-public sources, paradoxically, at a time when private investment in research is increasing.

Recent announcements by Chevron Corporation in the US signal a potential future expansion in privately funded energy research, with up to 100 new research personnel targeting new oil and gas supplies and energy sources.[14]

[14] Chevron Corporation USA, "Chevron to Open Energy Technology Centers in Aberdeen and Perth", *Press Release* 30 August 2006 <https://www.chevron.com/news/press/2006/2006-08-30.asp> (December 2006).

This, together with the dramatic increase of some 80% in private investment into general research seen in the two years from 2002-03 ($0.6 billion) to 2004-05 $1.1 billion) as reported by the ABS, suggests that with adequate infrastructure in place, critically-scaled research activity is expanding in areas targeted by the private sector as and when required.

From a national perspective, the latest ABS figures confirm that Commonwealth investment attracted to Western Australia in overall scientific research activity increased only slightly, in 2004-05, to 6.7% and remained low in proportion to its population base of 9.9%. This suggests that Western Australia can improve its capacity to win its share of Commonwealth investment particularly in strategic areas such as science infrastructure relevant to energy research.

Recommendation 1.
In partnership with industry and academe, and as part of an Energy Technology Innovation Strategy, scope and plan the science infrastructure needs, including human capital needs, relevant to the development of world-scale research activity to 2015.

- Collaborative research

Cooperative Research Centres
Since 1990, the primary avenue for nationally collaborative research in Western Australia is through Cooperative Research Centres established through the Commonwealth program.[15] Current relevant CRCs are noted on page 9 of this report.

An application for a proposed CRC for Future Farm Industries has been shortlisted for consideration shortly by the Commonwealth and draws from the existing CRC for Plant-Based Management of Dryland Salinity based in Western Australia. [16] The proposed new CRC plans to develop strategies to increase sustainable agricultural output, including woody biomass, through perennials.

Successful applications to the current round of CRC Program are being considered for announcement in December 2006.

National Collaborative Research Infrastructure Strategy (NCRIS)
National infrastructure development through the Biotechnology Products – biofuels program of the Commonwealth's National Collaborative Research Infrastructure Strategy (NCRIS)[17] is emerging as a new vehicle for

[15] Department of Education, Science and Training, *Cooperative Research Centres* https://www.crc.gov.au/Information/default.aspx> (December 2006).
[16] *CRC for Plant-Based Management of Dryland Salinity* <http://www.crcsalinity.com/index.php> (December 2006).
[17] Department of Education, Science and Training, *National Collaborative Research Infrastructure Strategy*

collaboration between national research bodies. Murdoch University with its research capacity in biotechnology, waste management and renewable energy are collaborating nationally in the development of biofuels and

State initiatives

Recent State initiatives draw from the government's clear priority areas for research set in recent years.

Understanding the vast marine environment including its vital relationship to climate change in Western Australia has been a focus of targeted public investment of $21 million, in 2005, with the establishment of the Western Australian Marine Science Institution (WAMSI).[18] WAMSI comprises twelve collaborating research parties from academe, Commonwealth research bodies and relevant State agencies.

NATIONAL ENERGY TECHNOLOGY TRANSFER AND DEPLOYMENT INITIATIVES

- Commonwealth investment profile

A recent summary by COAG of potentially available Commonwealth funding for future energy technology demonstration highlights "energy efficiency" as the most prominent area for investment in deployment initiatives (Figure 5).[19] This is followed by geosequestration and brown coal initiatives with fuel cells, wind, geothermal, and wave initiatives barely evident on the support horizon. Nonetheless, as noted throughout this report, some of these less supported energy options have particular relevance in Western Australia.[20]

<http://www.dest.gov.au/sectors/research_sector/policies_issues_reviews/key_issues/ncris/> (December 2006).

[18] *Western Australian Marine Science Institute* <http://sponsored.uwa.edu.au/wamsi/research> (December 2006).

[19] Op Cit. 6.

[20] Op Cit. 6.

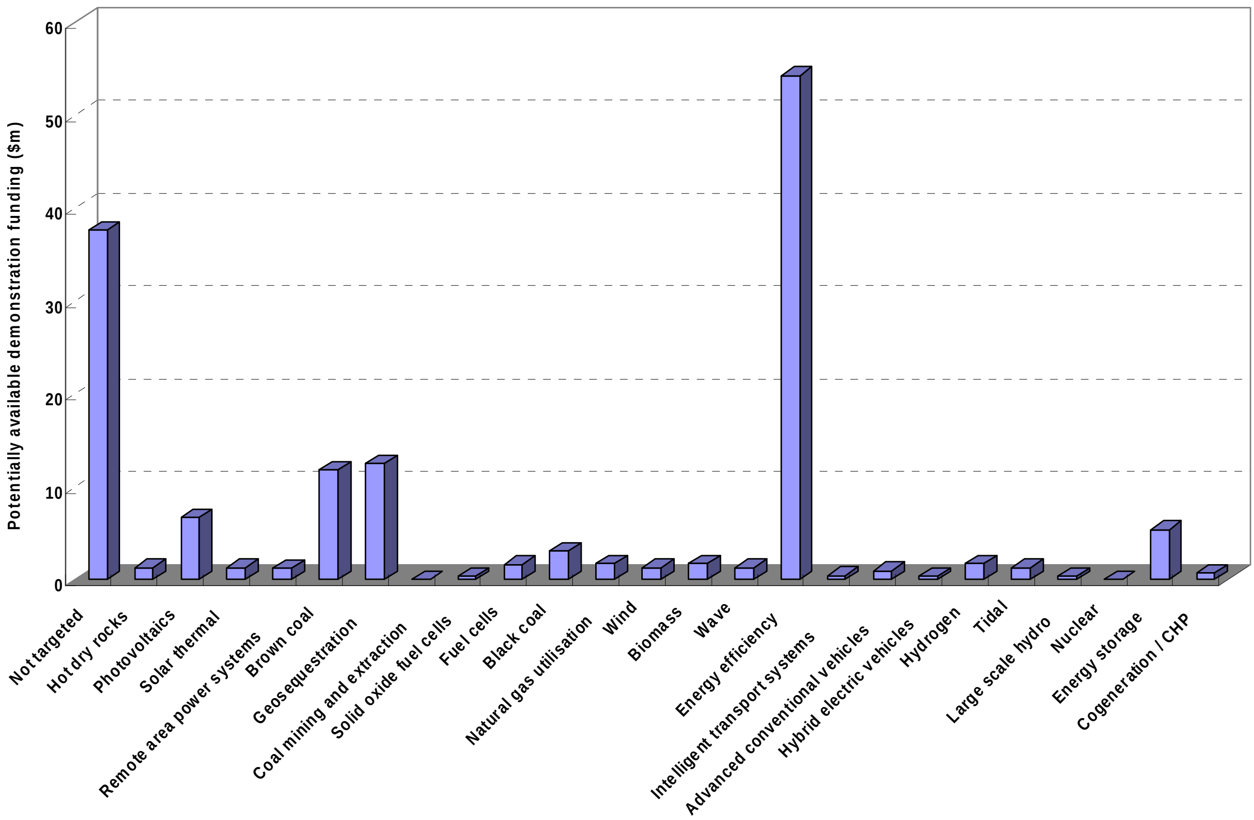

Figure 5. Estimated funding for energy technology demonstration.
Source: COAG Climate Change Group Report, 1 June 2006

Specific programs developed by the Commonwealth which target technology deployment over the next ten years in areas relevant to Western Australia include the Solar Cities program and the Low Emissions Technology Development Fund.

- Solar Cities Program

Solar Cities, a program established, in 2004, with a $75 million investment by the Australian Greenhouse Office (AGO), will trial, across four locations, how solar power, smart meters, energy efficiency and new approaches to electricity pricing can combine to provide a sustainable energy future in urban locations throughout Australia.[21] Bids from consortia based in Perth and Kalgoorlie have been shortlisted among eleven under consideration by the AGO.

Recently, the Commonwealth announced significant investments from the program: $15 million grant to South Australia's North Adelaide bid to install solar panels in more than 1,700 homes, along with and 7,000 smart meters; $15 million has also been granted for Queensland's Townsville bid to install about 1 MW solar photovoltaics, 2,500 smart meters and 1,600 energy displays to monitor residential energy data.

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[21] Australian Greenhouse Office, Dept of the Environment and Heritage, *Solar Cities - A Vision of the Future* <http://www.greenhouse.gov.au/solarcities/index.html> (December 2006).

In November 2006, the Prime Minister announced a commitment of $15 million to Blacktown, NSW, to assist in the installation of some 860 photovoltaic systems of varying sizes and 2,100 solar water heaters.[22]

The $45 million committed so far is expected to deliver 3,000 solar photovoltaic panels, 2,400 solar hot water systems, 13,500 smart meters, 6,000 energy efficiency consultations and 70,000 energy efficiency packs. At the time of reporting, any Commonwealth support was yet to be announced for the two Western Australian shortlisted bids from the remaining $30 million of program funds.

- Low Emissions Technology Demonstration Fund (LETDF) projects

This $500 million fund was established, in 2005, to foster technology that is to be commercially available by 2020 to 2030 and have the potential to reduce Australia's energy sector emissions by at least two per cent per annum over the longer term. [23] Recent investments from the fund have been made in clean coal and carbon capture and storage or geosequestration technology as noted below:

Clean Coal
The Commonwealth will provide $50 million from the *LETDF* to Queensland Government Corporations, CS Energy and Stanwell, along with project partners, including CCSD and CO2CRC, for a world-first Oxy-Fuel Demonstration Project to retrofit one of the power plants at Callide A to oxy-firing. The $188 million demonstration project will commence in 2007 and be completed by 2015. The resulting exhaust carbon dioxide will be captured, liquefied, transported and stored underground (geosequestration) at drilling test sites within 350 km in the Springsure/Emerald area.[24]

In 2006, the Commonwealth granted $50 million towards a $360 million pilot for a brown coal drying and a post-combustion carbon dioxide capture and storage project at International Power's Hazelwood facility in Victoria; construction will begin in 2007 with completion by the end of 2009.[25]

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[22] Prime Minister of Australia, "Blacktown First Solar City In NSW", *Media Release* 13 November 2006 <http://www.pm.gov.au/news/media_releases/media_Release2243.html> (December 2006).

[23] Australian Greenhouse Office, Dept of the Environment and Heritage, *Low Emissions Technology Demonstration Fund* <http://www.greenhouse.gov.au/demonstrationfund/> (December 2006).

[24] Macfarlane, Ian, "$125m To Lower Emissions in Queensland", *Media Release* 30 October 2006 <http://www.ausindustry.gov.au/content/content.cfm?ObjectID=E6844763-72A0-4DE3-B0231AABF4004FC5&L2Parent=97F89BF6-D01B-42CA-A601E5E9369062A9&L3Parent=91D6ABB3-F538-4876-BE254798CF2A1BC9> (December 2006).

[25] Macfarlane, Ian & Costello, Peter, "$125M Towards A Lower Emission Future", *Media Release* 25 October 2006 <http://www.ausindustry.gov.au/content/content.cfm?ObjectID=ACCA1CF7-5900-4367-AA43BE6D0323ECD6&L2Parent=97F89BF6-D01B-42CA-A601E5E9369062A9&L3Parent=91D6ABB3-F538-4876-BE254798CF2A1BC9> (December 2006).

Geosequestration
In November 2006, the planned Gorgon natural gas project in Western Australia received $60 million from the LETDF program for a commercial scale demonstration plant to store the CO_2 component of natural gas in deep reservoirs 2.5 km underground at Barrow Island. [26] The project is expected to inject 2.7 million tonnes of liquified CO_2 annually but is contingent on planning approvals expected, in 2007, with production scheduled for 2012.

The Fairview Power Project to extract methane from coal then bury the carbon dioxide emissions from power generation, will receive $75 million from the Commonwealth to build a new power plant at Injune, near Roma, Queensland. The methane will fuel a 100 MW power station and the CO_2 will be captured and injected back into the coal seam. The total life-cycle cost of this project is $445 million with commencement in April, 2007, and completion by 2015.

- Energy technology deployment initiatives in Western Australia

The deployment of relevant emerging technologies has seen significant pilot initiatives designed to test the technical and commercial feasibility under local conditions. Many technology deployments have drawn also from a diversity of renewable energy sources. Recent technological developments flowing from public and private sector initiatives in Western Australia include:

Separation of liquid CO_2
A Curtin University of Technology spin-off company, Cool Energy Ltd, established a trial facility near Dongara, in 2006, to cryogenically separate liquid CO_2 from natural gas streams.[27]

Conversion of methane to hydrogen or syngas
Local research by the University of Western Australia into the catalytic conversion of methane to hydrogen, carbon and/or carbon monoxide (syngas), is nearing development in partnership with Wesfarmers Ltd and US capital firm, XL Technology Group.[28]

Woody biomass gasification
In 2005, Verve Energy and CSIRO completed a 1MW plant in the Wheatbelt for the conversion of woody biomass to renewable power using CSIRO technology. See also page 28.

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[26] Campbell, Ian, "$60 Million for world's largest carbon capture and storage project", *Media Release* 23 November 2006 <http://www.deh.gov.au/minister/env/2006/mr23nov06.html> (December 2006).
[27] "Cool Energy Trial Underway in WA" *Oil & Gas Australia*, June, 2006, p14. <http://www.coolenergy.com.au/instant_news/attachments/0606%20Oil%20&%20Gas%20Australia.pdf> (December 2006).
[28] XL Technology Group, *Pipeline of possible opportunities* <http://www.xltechgroup.com/html/activity/pipeline.asp> (December 2006).

Geosequestration of CO_2
The Gorgon project partners are planning a commercial scale demonstration plant to store the CO_2 component of natural gas in deep reservoirs, 2.5 km underground at Barrow Island. The project is expected to inject 2.7 Mt of liquefied CO_2 annually beginning in 2012. (See also page 17).

Wave energy
In 2005, Renewable Energy Holdings Plc commenced trialling of a wave power and desalination prototype known as the CETO wave energy generator off the Fremantle coast, generating some 100kW. (See also page 30).

Wind energy
Western Australia continues to successfully deploy wind turbine technology both off- and on-grid. In addition to Western Power's (now Verve Energy) wind power installations since mid 1990s, the largest deployment is now Alinta's 90MW facility near Geraldton, established in 2005, and the most recent, an 80MW plant, established in 2006, by Griffin Energy/Stanwell Corporation at Emu Downs. (See also page 22).

Solar energy
In addition to a small 25kW photovoltaic system deployed in Kalbarri, in 1995, Verve Energy deployed a 20 kW photovoltaic trough concentrator system at Rockingham with grid connection in 2000. (See also page 21).

The continued deployment of new technology/processes will improve the diversity of energy sources, enhance regional development and gradually lower the cost base as the learning process unfolds. Having consideration the the diverse geographic characteristics, the identification of suitable sites for future deployments would ensure optimum planning outcomes for the future.

Recommendation 2.
In partnership with industry, identify suitable sites for the early deployment of demonstration plants for the following processes/technologies: geothermal, geosequestration, wave power, photovoltaics, efficient coal conversion, and biofuels from sewage and cellulosic wastes.

REVIEW OF LOW EMISSION ENERGY TECHNOLOGY PROSPECTS

- Mono-carbon fuels: methane, methanol and syngas

Methane
With its abundant endowments of natural gas reserves containing over 80% methane, Western Australia is well positioned to adapt to lower emission energy demands. The combustion of methane offers higher thermal efficiencies, lower emissions and lower capital costs compared to coal-fired plants, but its preference as a transition fuel is significantly escalating price. At an average 42% energy efficiency, combined cycle natural gas turbine(CCGT)

-fired energy production is highly competitive at USD 4–6/GJ, at 2005 gas prices ($0.02 – 0.03/kWh).[29] Natural gas fuel costs, however, now represent some 60-85% of total electricity generation costs associated with CCGT and research is focused on achieving higher efficiencies.

Escalating prices for natural gas also suggest higher value applications in the longer term, such as a feedstock of relatively pure methane in chemical manufacture through the versatile intermediate, syngas (see below).

Methanol
Conversion of methane to methanol is a mature technology and current research focuses on improved efficiency. Methanol is a stable liquid and offers a convenient form of energy storage with ready applications also in fuel cells. Nonetheless, methanol is toxic and mixes readily with water which requires a managed containment provision for large scale uses. In Australia, the technology is being adapted for the production of methanol from stranded natural gas reserves, a process currently being trialled in Victoria by Perth-based Coogee Chemicals.[30]

Syngas
Synthesis gas (syngas) in its purest form is a mixture of carbon monoxide (CO) and hydrogen (H_2) and is produced from a wide variety of hydrocarbon sources and water at high temperatures (250-800^{o}C) through a mature catalytic process known as “steam reforming”. Syngas itself is a highly versatile feedstock for the production of many chemicals and fuels in use today.

Methane from natural gas is a proven, viable feedstock for syngas. A future scenario for adding value to natural gas could benefit from the application of renewable solar thermal energy to convert methane to high value chemicals as described on page 20.

- Solar: thermal, PV and CSP

Photovoltaics
Electricity derived from the direct conversion of light by semiconductors, is termed photovoltaic (PV) power. Total global PV capacity is in excess of 1400 MW and deployment rates are growing at 15% annually. Funding schemes and feed-in tariffs to power grids have played an important role in the development of PV industries in many countries. However, conventional PV systems are based on crystalline silicon modules which account for some 60% of system prices. Nonetheless, the current price for PV modules of USD2,000-3,000/kW has dropped by some 15% per doubling of market size

[29] OECD. International Energy Agency *Energy Technology Perspectives 2006: Scenarios & Strategies to 2050* (France : IEA, 2006), p 177.
[30] *Coogee Chemicals* <http://www.coogee.com.au/op_meth.html#generation> (December 2006)

and new developments, such as thin-film on glass technology panels, anticipate cost reductions to less than USD500/kW.[31]

PV electricity generation operates at low efficiencies (6-15%) but offers several benefits as a developing distributed generation technology where it: readily integrates into urban landscapes; reduces electricity infrastructure costs and investment; assists in securing energy supplies; offers low operating and maintenance costs (1-3% of capital); and operates at near zero greenhouse emissions.

The Commonwealth's Photovoltaic Rebate Program was established, in 2001, and extended, in 2005, until June 2007, to generate some 11,000 PV installations. It offered a rebate of $4.00/peak Watt of installed PV capacity up to a cap of $4,000 per householder.[32] Total installed PV power in Australia is now about 40MW with 89% off-grid and 65% dedicated to non-domestic uses. The balance, equivalent to some 10,000 domestic residents have PV systems installed.

With access to vast areas of high solar flux, solar electricity is acknowledged as having significant potential to provide electricity for Australia. According to the PV Industry Roadmap, Australia could install capacity of 6,740 MW by 2020.[33]

The vast remote regions of Western Australia that do not have access to grid infrastructure are particularly suited to PV systems. However, off-grid PV capacity remains relatively small with a 31kW installation in Hamersley, in 2005, and a 32kW installation in Laverton, in 2006. [34]

Concentrating solar power

There are various means of concentrating solar energy to improve efficiency of solar systems, including thermal and PV generators, now under development. Currently, the IEA estimates that concentrating solar power (CSP) at optimum locations on either side of the Earth's equator costs USD0.10 - 0.15/kWh, or $0.13 – 0.20/kWh, with targeted future reductions to USD 0.05 - 0.08 over 10 years.[35]

In targeting solar power costs at $0.05/MWh by 2025, a private Victorian company, Solar Systems, has developed breakthrough photovoltaic cells able to withstand high temperatures, at which they convert a wider band of the sun's light directly into electricity at about 35% transformation efficiency.

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[31] Op Cit. 29, p 130
[32] Australian Greenhouse Office, Dept of the Environment and Heritage, *Photovoltaic Rebate Programme* < http://www.greenhouse.gov.au/renewable/pv/index.html > (December 2006)
[33] Australian Business Council for Sustainable Energy (BCSE) T*he Australian Photovoltaic Industry Roadmap* (Victoria : BCSE, 2004) <http://www.bcse.org.au/docs/Publications_Reports/PV%20Roadmap-web.pdf> (December 2006).
[34] Sustainable Energy Development Office, *Major WA Initiatives* <http://www1.sedo.energy.wa.gov.au/pages/waproj.asp> (December 2006).
[35] Op Cit. 29, p 227.

Although the technology is at the demonstration phase, with support from $75 million LETDF grants announced in October 2006,[36] the company will build a $400 million, 154 MW power station, which is expected to generate annually 270,000 MWh, sufficient for 45,000 homes in the Mildura region. The facility uses sun-tracking mirrors (heliostats) to concentrate sunlight from six large areas covering 600ha to 800ha. The first power will come on stream in 2008 and reach full capacity by 2013.

In Western Australia, Verve Energy explored the potential for CSP with the deployment of a small 20 kW photovoltaic trough concentrator system at Rockingham with grid connection in 2000.

Thermal
The CSIRO Solar Tower planned for construction near Mildura in northern Victoria, consists of a 5km diameter glass or plastic "apron" that feeds air, heated by solar radiation, into a 0.5-1km high tower, with one or more turbines coupled to electricity generators at the base of the tower. The design capacity of the system is 200MW of electricity. The design requirements have evolved to smaller sized units with continued research. The Solar Tower concept needs to be installed in regions with high solar input and is ideal for many parts of WA, especially in the state's wheatbelt and in regional towns such as Kalgoorlie.

The current plants in operation achieve costs of $0.16/kWh, the lowest of any solar technology and can be combined with fossil fuel-fired boilers to deliver power at $0.10/kWh.

According to CSIRO, solar thermal energy can also be applied to the production of syngas by methane reforming, incorporating 26% of the solar energy into the product gas.

- Wind

IEA member countries increased wind power capacity from 2.4GW, in 1990, to 28.1GW, in 2002. This represents a sharp annual growth rate of 23% over 12 years, with USD7.3 billion of wind projects being built, in 2002 alone. Driven by increasing natural gas prices, in 2005/6, the US installed a further 2.5GW of wind power and some suggest that wind energy could contribute 6% to the nation's energy mix by 2020.[37] Wind energy installed costs have steadily reduced by some 5% per annum and are expected to reduce further as technology refinements and installed capacity grow. The IEA advises that the most cost effective plants now produce power at USD0.03 – 0.04/kWh or $0.04-0.05/kWh.[38]

[36] Op Cit. 25.
[37] Eckhart M**,** "Renewable energy industry: 2005 review/2006 outlook" *Power Eng.,* 2006, 110(1), 8.
[38] Op Cit. 29, p 129..

In Australia, 184MW of wind capacity was installed to 2004, generating enough energy for some 83,000 Australian homes. It is understood that there is a further 2800MW, enough for over half a million households, of wind generation in the planning stages requiring a $5 billion investment.

Australia's first commercial wind power farm was constructed by Western Power at Esperance, in 1993, followed by the then largest wind farm at Albany, in 2001. A world-first wind-diesel hybrid system has since been installed at Denham which caters for the intermittency of wind.

Western Australia has currently installed about 195MW of wind power generating capacity with the largest now being Alinta’s 90MW facility near Geraldton, established in 2005, and the most recent, an 80MW plant, established in 2006, by Griffin Energy/Stanwell Corporation at Emu Downs.

Grid-linked wind power generation incorporates mature technology to deliver competitive power at near zero emissions. Further technological gains, particularly in power management, are expected to deliver better cost outcomes in the future. With increasing wind forces expected from climate change and a vast coastline (20,800km), Western Australia is well placed to benefit from this renewable energy source through further deployments.

- Clean Coal

In 2003, coal fired power generation was responsible for 32% of Australia's total GHG emissions and reductions in emissions are anticipated through improved efficiency. Geosequestration technology, now at the demonstration stage in Australia, is expected to improve prospects for continued use of coal in large-scale power generation.

Coal fuel in Western Australia, accounts for some 40% (compared to 77% for Australia[39]) of total power generation with 50% of the energy used in the mining and production of alumina, nickel and iron.[40] Average efficiencies in power generation from coal are currently at about 35%, with the best efficiencies achieved being 45-47%.[41] The CCSD, however, believes advancements in the following clean-coal processes can generate electricity at higher efficiencies in the range 42-55%: Ultra-supercritical (USC); Oxygen combustion (oxyfuel); Integrated Gasification Combined Cycle (IGCC); and Pressurised Fluidised Bed Combustion (PFBC).[42] Of these, UFC appears to offer the highest efficiencies into the future, with little market penetration expected for PFBC.

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[39] Op Cit. 17?

[40] Australia. Cooperative Research Centre for Coal in Sustainable Development *Research Snapshots 2004-2005* p 11 <http://www.ccsd.biz/ResearchSnapshots04-05.pdf> (December 2006).

[41] Op Cit. 29, p 118.

[42] Op Cit. 19, p.2?

Higher thermal efficiencies are the most practical way of reducing CO_2 emissions for the coal industry. CSIRO's summary, in Figure 6, depicts the quantifiable reductions in emissions resulting from the improved efficiencies offered by the various clean-coal processes. Although, there remains a significant gap in emissions when compared to the gas turbine processes.

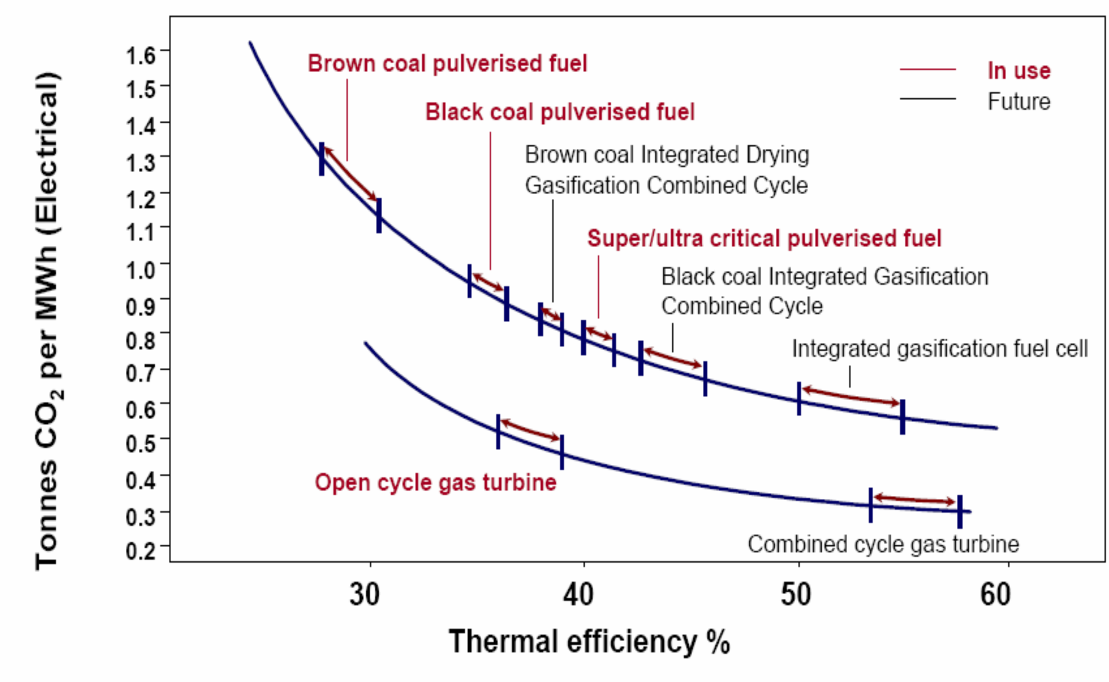

Figure 6. Summary of CO_2 emissions and thermal efficiencies for coal-fuel processes.
Source: D Harris, CSIRO, September 2006.

According to CSIRO Energy Transformed Flagship's research into low emission electricity, future technological developments include:

- the widespread retrofitting of post combustion capture equipment on existing coal fired power stations, commencing from 2010;
- the widespread introduction of clean coal technologies such as integrated gasification combined cycle power plants, commencing between 2010 and 2020; and
- the development of viable sequestration methodologies for commercial introduction, within the next 20 years;[43]

- Geothermal

Hot dry rock energy results from the decay of radioactive isotopes in granite located 3km or more below the surface. This decaying process releases significant amounts of heat (geothermal energy), which is then trapped by other insulating rock structures located above.

Pumping water through the hot rocks at about 300^{o}C, at depth, generates superheated water in a continuous geothermal energy process. The

[43] Commonwealth Scientific and Industrial Research Organisation (CSIRO), Energy Transformed Flagship, *Flagship research into low emission electricity* <http://www.csiro.au/csiro/content/standard/ps12k,,.html> (December 2006).

superheated water can then be used to drive conventional electricity generator turbines through direct conversion to steam or through secondary steam generation via a heat exchanger.

Geothermal energy production draws largely from proven technologies and engineering processes, such as drilling and hydraulic fracturing used in conventional oil and gas recovery. Nonetheless, hot dry rock geothermal systems are at the research and demonstration phase where the significant drilling costs associated with reservoir assessment and development represent 30-50% of project costs. One of the most promising projects internationally, Switzerland's Deep Heat Mining project, commenced in 1996 and is targeting pilot trial power generation by 2010.[44]

According to the Australian National University, there are significant reservoirs of geothermal energy available from hot dry rocks in Australia. These have been mapped and are depicted in Figure 7.[45]

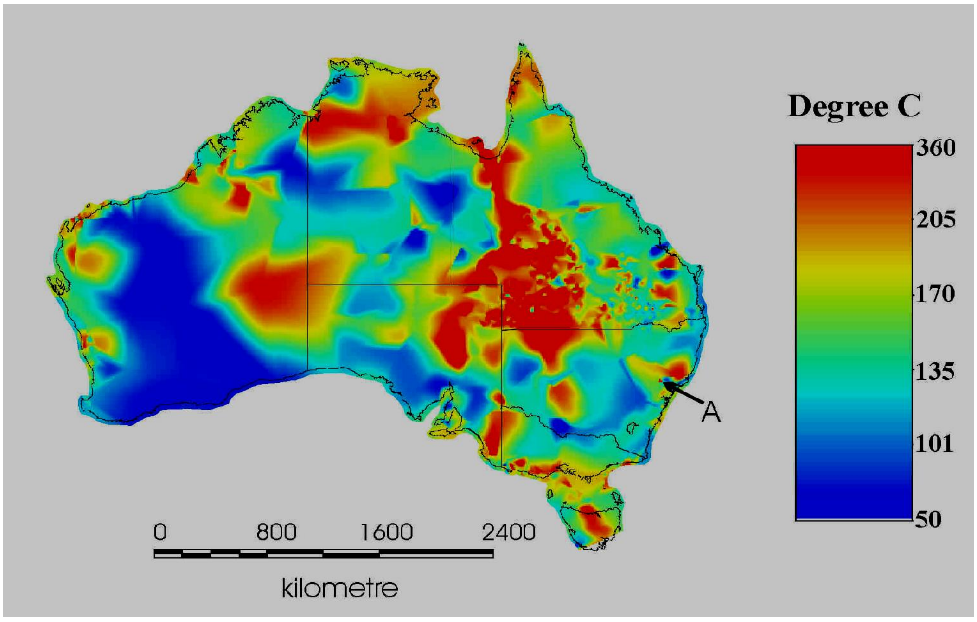

Figure 7 . Estimated hot-rock resevoirs to 5km depth across Australia.
Source: D Chopra, Australian National University, 2003.

Whilst geothermal reservoirs appear more limited in Western Australia, the most practical locations are those containing hot rocks in close proximity to the electricity grid and electrical load, such as within the Perth Basin.

Among some 14 companies investigating geothermal energy, an Australian publicly listed company, Geodynamics Ltd, has established a 13MW demonstration plant at Cooper Basin in South Australia. Projected power

[44] Swiss Deep Heat Mining Project, *A Deep Heat Mining plant is feasible in Switzerland* http://www.dhm.ch/dhm-swiss.html> (December 2006).
[45] ANU, *Hot Rock Energy: The Resource* <http://hotrock.anu.edu.au/resource.htm> (December 2006).

generation costs from hot dry rock geothermal plants, in Europe, are estimated by the IEA to cost USD0.24 – 0.36/kWh or $0.32 – 0.48/kWh.[46]

Whilst at the early demonstration phase, technically, hot dry rock geothermal energy can deliver stable base-load power generation at near zero greenhouse emissions. This is in contrast to other renewable energy sources that typically suffer intermittency.

In 2006, Geoscience Australia is understood to be investigating onshore geothermal reserves with a provision of about $60 million. Given its future potential for base-load power, it is surprising that there appear to be no geothermal energy developments underway as yet in Western Australia and a detailed evaluation of any impediments is suggested.

In November 2006, the State announced that it would call for expressions of interest from companies wanting to explore for and harness power from granite rock deposits as part of a new climate change action plan currently being developed. [47]

Recommendation 3.
Review any regulatory or technical impediments to the development of geothermal power in Western Australia.

- Hydrogen

Hydrogen is the lightest gas, is readily oxidised and some 50 Mt annually are produced globally from natural gas (48%), from oil (30%), from coal (18%) and from water by electrolysis (4%) releasing oxygen as a valuable by-product.[48] Hydrogen can be used as a fuel, releasing only water, by either combustion or electrochemical oxidation in fuel cells. Existing hydrogen pipelines in Europe and the United States indicate a proven means for the production, storage and transport of hydrogen on a large scale.

Where the electricity used, in turn, is sourced from intermittent sources of renewable energy, such as solar photovoltaic or wind energy, hydrogen can serve as a transformer and store of energy, with near zero net emissions of GHG. Hydrogen's role as a store of energy is currently being explored at the demonstration stage at UK's 4MWh HARI. [49]

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[46] Op Cit. 29, p 218.
[47] Carpenter, Alan, "Hot Rocks to Cool Global Warming", *Government of WA Ministerial Media Statements* <http://www.mediastatements.wa.gov.au/media/media.nsf/3c64c0ab7409c18f48256dbe0025d27c/740c4a45366294cc4825722900149fb6?OpenDocument> (December 2006).
[48] Op Cit. 29, p 291.
[49] Centre for Renewable Energy Systems Technology (CREST) *Hydrogen and Renewables Integration (HARI)* (UK : Loughborough University, 2006) <http://www.ieahia.org/pdfs/HARI.pdf> (December 2006).

Currently, most hydrogen is generated by steam reforming of increasingly costly natural gas, generating considerable CO_2 in the process. Over the next few decades, coal could become the preferred feedstock with the prospect of long-term storage of CO_2 in deep coal seams. Nonetheless, recent technological refinements dwell on the optimisation of hydrogen production by steam reforming of a wide range of hydrocarbons including biomass.[50] Roadmaps toward a hydrogen-based economy, developed by the EU and by the US government, indicate a long-term time frame extending to 50 years.

Alternative technology such as thermochemical decomposition (also known as thermolysis) of water also produces hydrogen and oxygen at temperatures above 1500^{o}C. This may serve as an alternative to electrolysis with applications suited to power plants should reductions in operating temperatures be achieved.[51]

Despite the substantial research effort underway on a range of fronts, hyrdrogen fuel for stationary energy is not expected to be viable option in Western Australia until the long-term.

- Fuel cells

Fuel cells comprise of electrochemical reactions where energy resulting from a fuel oxidation is converted into electrical energy. In an organic/air fuel cell, electricity is produced when fuel such as methanol, formaldehyde, or formic acid is oxidised to carbon dioxide at an anode, while air or oxygen is reduced to water at a cathode. Conceptually, the process may be reversed by applying electricity to produce methanol from CO_2 and water. Such a process would serve as a method of storing energy and recycling CO_2, in what may be termed a methanol economy.

Reversible fuel cells, employing organic fuels such as methanol, would be suited for stationary applications, because of the high specific energy of organic fuels (specific energy of methanol is 6.232 kWh/kg), the ready storage of energy as a stable liquid, suiting existing infrastructure, and the future prospect of sequestering CO_2 in the production of a renewable fuel.

Hydrogen can also serve as a fuel in fuel cells and, in highly pure form, is used in the hydrogen bus trial currently underway in Perth.

As with many energy processes, the foremost technical challenge in the development of organic fuel cells is one of efficiency improvement, particularly how to efficiently separate CO_2 from other gases. Accordingly, fuel cells are not expected to pose a viable option in Western Australia until beyond 2030.

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[50] Edlund D J, Herron T G, “Steam reforming method and apparatus incorporating a hydrocarbon feedstock” US Pat. 7005113.
[51] Forsberg, C. W., "Hydrogen, Nuclear Energy, and the Advanced High-Temperature Reactor", *Int'l J. Hydrogen Energy* 2003, 28, 1073-1081.

- Biomass and biofuels

Biomass is the organic matter of biological sources, typically plants and organisms. In the process of photosynthesis, growing plants capture solar energy and sequester carbon dioxide from the atmosphere to form carbohydrates which serve as an important source of useable energy. This energy can be released directly by combustion or transformed by biological fermentation processes into a range of storable biofuels with higher energy density than the source biomass, such as methane, methanol, ethanol, dimethyl esters or oils, including animal tallows, otherwise termed, biofuels. The carbon dioxide released following combustion of these fuels can be recycled with the recreation of organic biomass in the photosynthesis process. In a full life cycle, biofuel can therefore deliver solar energy in storable form with near zero net carbon dioxide emissions.

Whilst offering lower specific energy than petrol, the stability, ease of handling and storage offered by biofuels make them adaptable for stationary energy production. Furthermore, methanol burns more cleanly and efficiently than petrol in internal combustion engines and, in fuel cells, can generate electricity. These liquid fuels may prove a more convenient form of energy storage and transportation than hydrogen.

Methane and ethanol produced from fermentable waste or residual biomass already provide sustainable energy options where such biomass is sourced from centralised waste streams.

Direct Combustion of Biomass

Historically, combusted biomass from arid-land forestry was a primary source of energy for the eastern goldfields of Western Australia and central Queensland sugar mills. In the arid eastern goldfields, it was estimated that 23,000,000 dry tons of wood were harvested prior to 1919 from the "woodline", an area of about 1500 square kilometres serviced by light rail. This biomass was simply combusted at the rate measured, in 1908, of 230,000 dry tons per annum where 0.6 dry tons was used per ounce of gold produced.[52] Harvesting was quoted, in 1901, at the rate of 5 dry tons per hectare without forest denudation and with reserves estimated as sufficient for a 14 year-life, at which time petroleum and coal would be considered. For such a scenario to operate again today may require a balance in the trading of scarce potable water for afforestation and carbon biosequestration.

Even with its long history in Australia, biomass remains a minor contributor to the energy market. The exception is the use of residual cane trash (bagasse) in the sugar industry which relies on a tolerance of seasonal intermittency, high precipitation rates and highly articulated rail infrastructure. Low specific energy of biomass compared to petrol, harvesting and transportation cost factors, and supply intermittency have demonstrably limited biomass applications in stationary energy production.

[52]. Bianci P, Bridge P and Tovey R, "Early Woodlines of the Goldfields" Ed, Hesperian Press, 2006, p.ix, 1. This reference quotes what is assumed to be green tonnes which have been reduced by 50% to dry tonnes.

Nonetheless, in addition to its fuel uses, biomass production offers potential benefits including: nutrient stripping from municipal waste streams; regional employment opportunities; management of water tables and dryland salinity; shelter for stock; reduced soil erosion; increased biodiversity; and aesthetic value.

Currently, Australia derives about 9% of its stationary energy consumption from biomass; about 70% of this is in the form of process heat resulting from the sugar and wood processing industries. The balance includes biomass added in co-fired power stations.

It is estimated the cost of generating electricity from biomass ranges from USD 0.04 – 0.13/kWh ($0.05-0.17/kWh) depending on the degree of co-firing and co-generation.[53] However, such plants located near regional loads operate with lower transmission costs and are relevant to Western Australia's remote regions.

Western Power, now Verve Energy, recently completed a 1MW (x8,000hr/yr) demonstration plant, commissioned in 2005, using CSIRO's new fluidised bed gasification technology, which partially burns wood producing charcoal. Steam activation then converts the charcoal to activated carbon as a saleable co-product. Eucalyptus oil is distilled from the leaves and the spent leaves are gasified to fuel the boiler.

According to Verve Energy, in August 2006, a commercial scale plant of 5MW producing 40GWh would service 5,000 homes, cost about $5M and use 50,000 dry tonnes of biomass per annum. This would be sourced from about 20 million trees planted at the rate of 2600 oil mallee trees per hectare, occupying 7,700 hectares or 77 sq km. With the South West Interconnected Grid servicing to 838,997 customers over 322,000 sq km, such plants would be suited to servicing decentralised communities across the wheatbelt.

Transformation of biomass - methane and ethanol from waste steams

Anaerobic digestion by micro-organisms of waste biomass to produce methane (biogas) is now a mature process with many small installations across Australia having been established since the mid 1980s. Technological refinements are continuing, particularly in the improved digestion of fatty residues.

Locally, waste sewage biomass is currently being converted by anaerobic digestion to biogas by Organic Resources Technology Ltd and Water Corporation, with the methane component (at 50-60% of biogas) used to generate 6GWh of power annually. Such processes draw from a continuous supply of feedstock in centralised waste streams and can deliver continuous energy whilst reducing negatively-valued waste.

Another mature technology undergoing refinement is the production of ethanol from a range of biomass sources. Considerable debate has occurred over the

[53] Op Cit. 29, p 127

validity of ethanol from biomass as a net source of renewable energy.[54] A recent review provides a comprehensive analysis of the debate and points to cellulose and lignocellulose, sourced typically from waste biomass, as offering the best returns on investment when used as feedstock in the production of ethanol.

Current international research activity is targeting low-value renewable feedstocks for ethanol production, supported by investment from multinational petrochemical companies. According to the IEA, ethanol produced from lignocellulose sources such as stalks, bagasse, straw and wood, reduces the risk of food substitution, anticipated in more conventional ethanol-from-grain scenarios, by drawing from lower value agricultural and forestry waste streams.[55] The biotechnology and logistics for such a process remain at the early development phase, with eight demonstration plants ranging in capacity between 1-40 million litres of ethanol to come on stream, in 2006-07, largely in the US.

The technology for transformation of lignocellulose to ethanol is at an early stage of development internationally and could be competitively pursued locally, as suitable feedstock and research capabilities in biotechnology are available.

- Ocean Energy

With rising levels, temperature, acidity and rate of dynamic change of the oceans, the associated stored energy offers potential opportunities to access increasing reserves of renewable energy.

Wave power

With its 20,800km western coastline, the efficient transformation of wave energy offers a potentially limitless source of renewable energy in coastal Western Australia. It is believed by the World Energy Council that potentially two terawatts of electricity, twice the world’s current electricity production, could be sourced from wave power. Western Australia has one of the best opportunities to exploit this form of renewable energy. The yearly average wave energy flux per metre of wavefront is 78kW for Western Australia’s south west coast, and 76kW for the southern coast. This is in comparison to around 37-38kW for Australia’s eastern coast and 100kW for Hawaii. Whilst the technology is currently at the demonstration stage and costly, it has the potential to be further developed and used on a larger scale in the future.

In 2005, the London-listed public company, Renewable Energy Holdings Plc commenced trialling of a wave power and desalination prototype known as the CETO wave energy generator off the Fremantle coast, generating some 100kW.[56] The technology was developed by Perth company, Seapower Pacific Pty Ltd. According to company information, a wave farm of 125

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[54] Hammerschlag, R, **“**Ethanol's Energy Return on Investment: A Survey of the Literature 1990-Present” *Environ. Sci. Tech*., 2006, 40(6), 1744.
[55] Op Cit. 29, p 141
[56] Renewable Energy Holdings Plc <http://www.reh-plc.com/> (December 2006).

commercial CETO units could generate 18MW of electricity or supply 45 billion litres of potable water each year by desalination of seawater.

Tidal power (from Dr Hobbs, Office of Science and Innovation)
Tidal energy is the result of the interaction of the gravitational pull of the moon and, to a lesser extent, of the sun. In general, there are two tidal cycles per day. Tidal energy is significantly different to hydropower, which derives energy from hydrological climate cycles. Tidal energy is also different to wave energy, where energy is derived from short-term wave action rather than tidal action.
Tidal barges act in a similar way to hydropower schemes by trapping water behind a barrage across the mouth of an estuary or artificial storage and using the head difference as the tide changes to produce energy. Tidal barges require turbines that can produce power efficiently at variable head levels. This is unlike conventional hydro, which is designed for a relatively fixed head, particularly in low head applications.

Tidal energy has been previously considered in Western Australia at Derby. In 2000, the Commonwealth Government, through the Renewable Energy Commercialisation Program undertook a $1million due diligence study on Derby Tidal Project. However as with most tidal projects, the environmental impacts and the high capital cost of the proposed tidal system were believed to be unacceptable.

The cost of one proposed option of the Derby Tidal Project, the 5MW 4.35Mm^3 storage at Doctors Creek, resulted in an approximate cost of energy of $0.36/kWh for tidal energy, before the inclusion of capital cost grants or green energy benefits such as Renewable Energy Certificates.

- Fusion
(edited form of text by B Hobbs, Office of Science and Innovation)

Thermonuclear fusion offers the potential of an almost limitless source of energy for future generations but it also presents some formidable scientific and engineering challenges. It is called 'fusion' because it is based on fusing light nuclei such as hydrogen or lithium to release energy. The process is similar to that which powers the sun and other stars. Effective energy-producing fusions require that gas, from a combination of isotopes of hydrogen - deuterium and tritium - is heated to very high temperatures (100 million degrees centigrade) and confined for at least one second. One way to achieve these conditions is to use magnetic confinement. The most promising configuration at present is the tokamak, a Russian word for a torus-shaped magnetic chamber**.**

International co-operation has resulted in a $6 billion program announced in May 2006, to build the International Thermonuclear Experimental Reactor (ITER), which incorporates a number of key technologies essential for a future power station. ITER will be able to operate for very much longer periods (over 500 second pulses) and will help to demonstrate the scientific and technological feasibility of fusion power. Most importantly, it will be the first fusion device designed to achieve sustained burn - at which point the reactor becomes self-heating and energy producing. ITER is to be built at Cadarache, France, and is an international collaboration between the European Union, USA, Japan, the Russian Federation, China, South Korea, and India. It is based around a hydrogen plasma torus operating at over 100 million °C, and will produce 500 MW of fusion power. It is technically ready to start construction and the first plasma operation is expected in 2016.

The radiotoxicity of a fusion power station's waste materials decay rapidly to inert helium and present no accumulating or long-term burden on future generations or need guaranteed isolation from the environment for long timespans. In addition to these favourable results, fusion produces no climate-changing or atmosphere-polluting emissions.

As Australia is not a participant in the current developments, fusion power is not expected to become available until beyond 2050.

REVIEW OF EMISSIONS MANAGEMENT TECHNOLOGY

- CO_2 capture and storage technology outlook

High-intensity emissions of CO_2 from few sources are a characteristic of Western Australia’s emissions profile. These sources include power stations and cement kilns, both of which are currently fundamental to socio-economic function and are likely to increase their output in the future. The high intensity of emission can benefit from future carbon capture and storage technologies currently under development.

The WMO/UNEP notes, however, that for large stationary energy plants, carbon capture and storage within geological or ocean storage systems will require an additional 10-40 per cent of the energy solely for the capture and compression operations.[57] This could add $0.01–0.07 per kWh to the cost of electricity production. Retrofitting such systems to existing plant could introduce greater inefficiencies and cost.

The most cost effective technology option for continued fossil-fuel energy generation would see the co-development of power generation alongside proven geosequestration sites. Three CO_2 storage projects each storing more that 1 $MtCO_2$ are in operation in a saline formation in Norway, the Weyburn EOR project, in Canada, and the In Salah project in the gas fields of Algeria.

The Fairview Power Project to extract methane from coal then bury the carbon dioxide emissions from power generation will receive $75 million from the Commonwealth to build a new power plant at Injune, near Roma, Queensland. The project involves extracting methane from coal seams located too far underground to be mined. The methane will be burnt in a 100

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[57] Metz, B, Et al (eds), WMO/UNEP Intergovernmental Panel on Climate Change *Special report on carbon dioxide capture and storage* (Cambridge University Press, 2005), p 4 <http://arch.rivm.nl/env/int/ipcc/pages_media/SRCCS-final/IPCCSpecialReportonCarbondioxideCaptureandStorage.htm> (December 2006).

MW power station and the carbon dioxide emissions captured and injected back into the coal seam. The total life cycle cost of this project is $445 million, with commencement in April, 2007, and to be completed by 2015.[58]

These deployments indicate that the technology is maturing and suitable sites for geosequestration could also be identified locally in the near term to allow long term planning scenarios to be developed.

- Natural sequestration of CO_2

Biosequestration

The natural capture of CO_2 through photosynthesis to produce biomass is covered on page 26. The CRC for Greenhouse Gas Accounting has provided leadership in the analysis of carbon biosequestration in Australia since 1999.[59] A partial analysis of Western Australia's biosequestration capacity within its flora by the CRC was reported, in 2003, in an effort to identify opportunities in land management. The report, however, focused only on the southern areas of the State and did not consider the changes in precipitation arising from climate change and the biosequestration capacity of the northern areas.

At present, the carbon carrying capacity of the entire State is largely unquantified and a review of this potential having consideration of the anticipated impacts from climate change is suggested.

Recommendation 4.
In light of the modelled impacts of climate change relevant to Western Australia and the potential for biosequestration through offsets, undertake a review of the State's carbon storage capacity within its terrestrial flora to 2050.

Ocean storage of CO_2

The ocean covers 71% of the Earth's surface and acts as a vast sink of absorbed CO_2 in chemical equilibrium with the atmosphere; it contains about 50 times the carbon present in the Earth's atmosphere. About one third of anthropogenic CO_2 emissions, or 500 Gt (Gigatons), have been absorbed into highly diffused upper ocean layers over the past 200 years.[60] The rate of CO_2 absorption into the ocean is dependant upon temperature, alkalinity, dissolved mineralisation and atmospheric concentration or partial pressure. According to the WMO/UNEP and well established chemical equilibrium data, sustained

[58] http://www.ausindustry.gov.au/content/content.cfm?ObjectID=49DE916A-53FB-46B0-85154B9EB215812F&L2Parent=0786C9BE-08B7-4973-93429A645AEEC8E4&L3Parent=61B11DDD-1A32-42EE-9827BD5C63DE326D?

[59] *CRC for Greenhouse Gas Accounting* <http://www.greenhouse.crc.org.au/> (December 2006).

[60] Sabine C L, Feely R A, Gruber N, Key R M, Lee K, Bullister J L , Wanninkhof R, Wong C S, Wallace D W R, Tilbrook B, Millero F J, Peng T H, Kozyr A, Ono T and Rios A F, The oceanic sink for anthropogenic CO_2," *Science,* 2004, 305(5682), 367.

CO_2 atmospheric concentrations of 350-1000ppmv imply that 2,300 ± 260 to 10,700 ± 1,000 $GtCO_2$ can be stored in the oceans. [61]

When CO_2 dissolves in water it increases acidity only slightly but is thought to impact on sensitive marine ecology significantly. According to the Intergovernmental Panel on Climate Change (IPCC), over the past 200 years the increase in atmospheric CO_2 from 280ppm to 380ppm has caused oceans pH to decrease (being an increase in acidity) from pH8.2 to pH8.1. In the presence of dissolved minerals, insoluble mineral carbonate formation can occur and beneficially serve as a long term store of carbon.

With its vast coastline of some 20,800 km, Western Australia is well placed to research and understand the natural dynamics at play in the surrounding oceans through the recently established WAMSI. (See also page 13).

REVIEW OF ENERGY SUPPLY MANAGEMENT TECHNOLOGIES

- Energy Storage and distribution

Energy storage

Technologies associated with large-scale energy storage are important components in smoothing the intermittency experienced in power systems from most renewable energy sources. Energy storage in an electricity generation and supply system also enables the decoupling of electricity generation from demand.

The many technical possibilities being considered nationally at the research stage are reviewed comprehensively in a recent paper by the Australian Greenhouse Office.[62] Other than pumped storage hydropower, as yet, there are no significant technology deployments in Australia, although it is notable that the zinc-bromine flow cell battery developed with Murdoch University is being commercialised in the US by Australian and US listed public company, ZBB Energy Corporation, with 500kWh grid-interactive storage modules now on sale.[63]

In June 2004, the Commonwealth established a $20 million Advanced Electricity Storage Technologies program intended to support the better identification and promotion of relevant technologies, with successful applicants to be announced in late 2006. A contract has recently been awarded for the $14 million Wind Forecasting Capability programme. This will facilitate greater penetration of wind in energy markets and allow for more strategic planning of wind farms.

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[61] Op Cit. 57, Chapter 6: "Ocean Storage".
[62] Australian Greenhouse Office, Dept of the Environment and Heritage, *Advanced Electricity Storage Technologies Programme, Energy Storage Technologies: a review paper* (2005) <http://www.greenhouse.gov.au/renewable/aest/pubs/aest-review.pdf> (December 2006).
[63] ZBB Energy Corporation, *Advanced Energy Storage Solutions* <http://www.zbbenergy.com/products.htm> (December 2006).

Thermochemical storage, via CSP, of solar energy to convert methane to the more versatile and higher calorific-value syngas and downstream products, is a relevant technology in the medium-term, particularly, for Western Australia with its access to abundant solar energy and natural gas resources. CSIRO successfully completed a proof-of-concept demonstration system for this technology, and is now scaling up its Newcastle laboratories to a complete demonstration system that can be operated over long periods.

Recommendation 5.
Promote and support the development of technologies for the conversion of methane from natural gas into higher value applications such as methanol and syngas with the incorporation of renewable energy.

Energy distribution

In 2004-05, the electricity generated on the South West Interconnected System (SWIS) by Western Power was 28TWh distributed over a network covering some 322,000 sq km to 838,997 customers. The SWIS suffers a line loss of almost 2TWh through line resistance.[64]

The additional development of renewable energy generation from sources such as wind, biomass, solar and geothermal feeding localised demand along the grid could serve to reduce line resistance as well as emissions.

MANAGEMENT OF TECHNOLOGICAL RISK AND ADAPTATION

- The public policy paradigm

Evaluation of technological and economic risk is integral to the business case for public support or prioritisation of any new technological development, either through research or technology transfer. In view of the many complexities and uncertainties presented by climate change, an iterative approach to policy development offers the most reliable and practical means for regularly gauging the risk factors and rapidly changing cost structures ahead of implementing change. As further noted in a recent report to COAG, risk assessment and adaptation planning require multi-disciplinary analyses to understand the complex and highly technical science behind climate change.[65]

At a national level, COAG is considering the establishment of a $30 million Australian Climate Change Centre to serve as a centralised 'hub' of expertise for the evaluation, development and coordination of research priorities and to function as a 'research purchaser'. A suitable base of technical expertise in policy formulation and implementation in Western Australia, particularly at a

[64] Western Power Corporation <http://www.wpcorp.com.au/mainContent/theNetwork/AboutTheNetwork.html?> (October 2006).

[65] Allen Consulting Group *Managing Climate Research* (October 2006).

time of skills shortage, is important in building a considered and viable action platform to address technological change.

Historically, however, national science bodies are prone to overlooking more remote interests. Indeed, Western Australia has a generally poor record of winning its share of Commonwealth investment in research and development and endeavours to support its own needs whilst working to overcome any competitive disadvantage in winning Commonwealth support.

In view of the State's diverse geographic characteristics, expanding energy needs and important strategic interests, a dedicated energy technology policy development and implementation role is suggested for the science and innovation portfolio. Such a role would initially focus on whole-of government initiatives, such as the Energy Technology Innovation Strategy foreshadowed by the former Minister, in 2005, and would benefit from a review of the relevant legislative base.

- Lowering the risk for Western Australia

Technological learning curves and scale of deployment
Currently, Australia benefits from relatively low stationary energy cost which requires that any change to the technological means of production carries low risk and a definable, low impact on the cost base.

International experience of the various technological developments relevant to stationary energy highlight the most poignant observation that: real cost reduction in electricity production from developing technology is correlated to the cumulative installed capacity, that is, scale. This is well illustrated in the IEA's experiential learning curves based on the real observations made during the maturation of relevant technologies for wind, solar PV, biomass, gas and supercritical coal over the 15 years from 1980 – 1995 (Figure 6).[66]

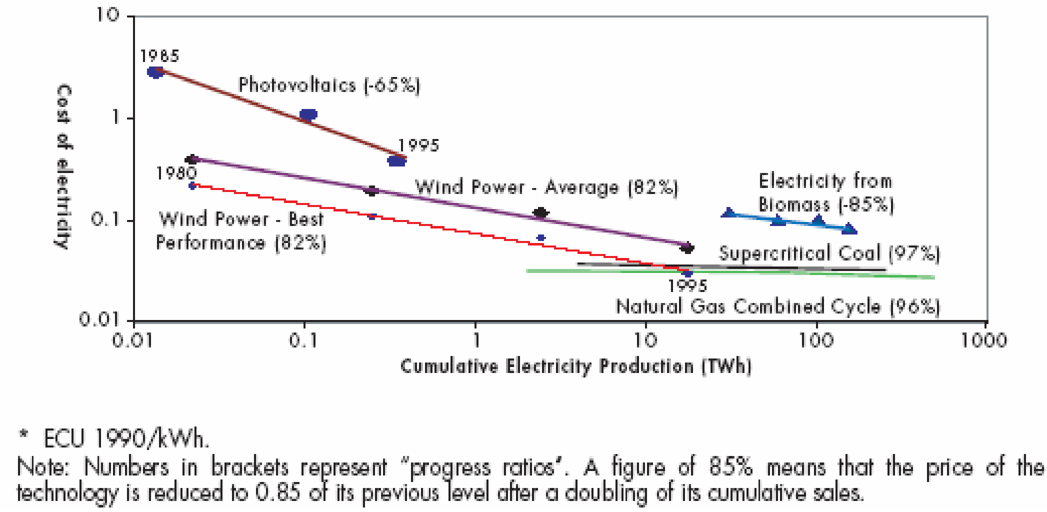

Figure 8. Experiential learning curves for power generation technologies from 1980-1995.
Source: International Energy Agency, 2000

[66] *Renewable Energy* <http://www.iea.org/textbase/papers/2002/renewable.pdf#search=%22iea%202001%20learning%20curves%22> p 8 (December 2006)

In charting a course to lower emission technologies locally, it is prudent to gauge the significant technical and economic risks associated with each of the plausible energy processes now at various stages of maturity.

A gauge of the Commonwealth's insight is now available in an estimate prepared for COAG in 2006, of potential funds for development of the various low emission processes/technologies (Figure 8). The Commonwealth's investment forecast targets energy storage, with at least eight other low-emission processes also identified for significant investment. This approach diligently recognises the intermittency and attendant risks of most renewable energy processes and serves to limit the risk of failure by focusing on generic solutions suited to several energy sources.

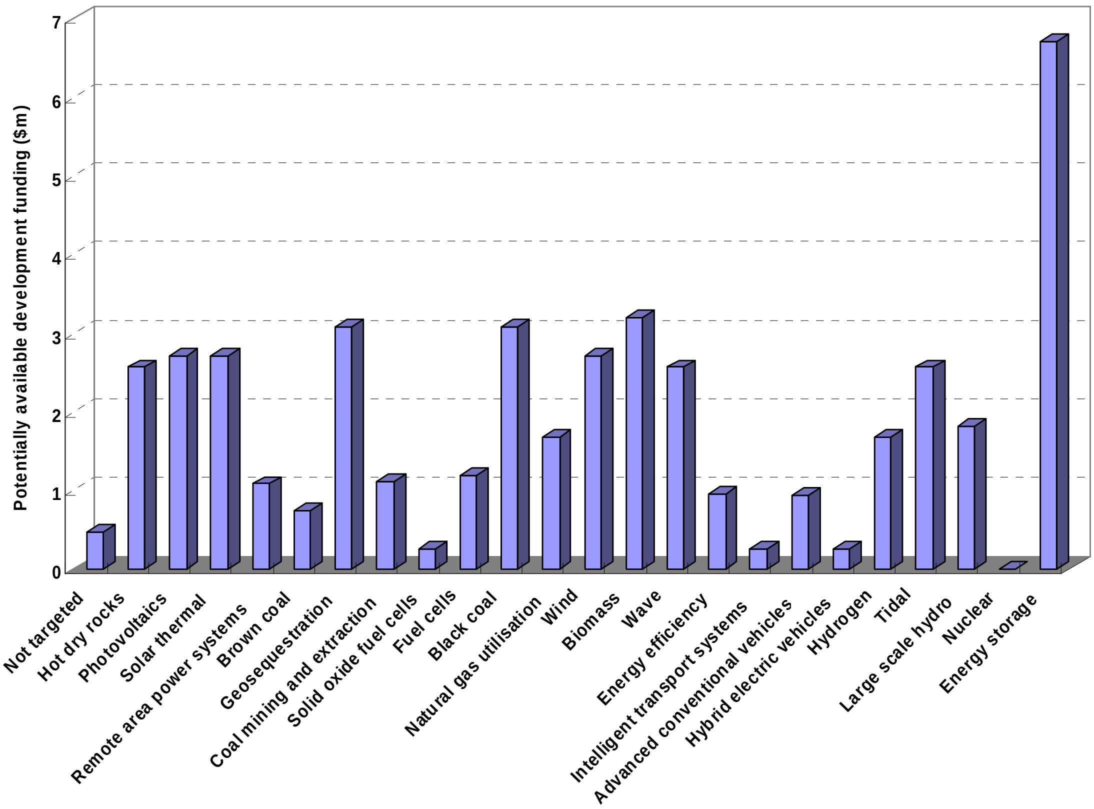

Figure 9. Estimated funding available for energy technology development.
Source: COAG Climate Change Group Report, 1 June 2006

Optimal progression to alternative energy generation technologies with lower emission is premised on avoiding inefficiency. As a rule, inefficiency is positively correlated to multiple-step processes which are best avoided in the design of technological solutions. For example, the compounding effect can reduce a series of seven otherwise highly efficient unit operations (operating at say 80% efficiency) to an inefficient overall transformation (to 21% efficiency) of the raw energy source.

Biomass options

Renewable biomass production options in Western Australia conceptually benefit from access to vast land mass, increasing CO_2 concentrations and high solar fluxes, but are limited by seasonal intermittency, potential displacement of food production, diminishing precipitation and declining access to suitable water resources. It is foreshadowed that biofuels could supply 30 per cent of global demand.[67]

However, a future increase in arid areas in Western Australia would argue against a production cycle of biomass for stationary energy if it were to compete for resources relevant to the food production cycle. This point was noted recently on a more global level by Hill et al.[68] The efficient conversion of large sources of negatively valued waste or residue streams such as sewage and lignocellulose, respectively, would pose as an exception that has relevance in Western Australia which, in spite of its large area, has substantial centralised sources of waste biomass.

The International Energy Agency reports that in 2004-05, in Japan, sewage dry matter (of calorific value of 24,000kJ/kg) has been co-fired in successful demonstration trials to a level of 1% substitution in coal fired power stations.[69] Locally, Water Corporation and Organic Resources Technology Ltd generate about 6GWh annually from anaerobic digestion of sewage biomass to produce methane (biogas).

The strength of wind

Comparisons of estimated average future cost reductions for renewable energy options, with direct transformation to electricity, have previously been made by the IAE and are summarised in the table at Figure 9.[70]

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[67] Koonin, S E., "Getting Serious About Biofuels", *Science*, 2006, 311(5760), 435, 435.
[68] Hill, J, Et al, "Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels" *Proc.Nal. Acad. Sci* 2006 103(30), 11206. <http://www.pnas.org/cgi/content/short/103/30/11206> (December 2006).
[69] OECD. IEA, Coal Advisory Board, *Case Studies in Sustainable Development in the Coal Industry* (France : IEA, 2006) <http://www.iea.org/textbase/papers/2006/CIAB_Case_Studies_2006.pdf> (December 2006).
[70] Op Cit 22?

	Current Cost	Cost Reductions by 2020
Bioenergy	High. Cost-effective in CHP applications with low fuel cost. Co-firing is a relatively low-cost retrofit option.	10-15%
Wind onshore	Relatively low; lowest compared to other renewables.	Up to 15-25%
Wind offshore	High.	20-30%
Solar Photovoltaic	Very high. Cost-effective only in niche markets.	30-50%
Solar Thermal	Very high.	30% +
Geothermal	High.	10%
Hydro	Relatively low for large hydro.	10%

Figure 10. Renewable energy comparisons of estimated future cost reductions to 2020.
Source: International Energy Agency, World Energy Outlook 2001

It is most notable that, whilst differing site conditions contribute to variation, cost reductions of 15-25% for onshore wind energy are anticipated from an already low cost base. Of the most applicable renewable energy options, wind energy, therefore, offers a lower risk scenario than does a biofuels scenario. Not only does wind energy deliver the lowest cost base and broad applicability to Western Australia's coastal region, but the comparative technological learning curve (see Figure 6) foreshadows higher prospective gains based on the present low cumulative capacity profile.

CSIRO's recent analysis also shows that wind and biomass deliver the lowest cost/emissions energy from renewable sources (Figure 10).

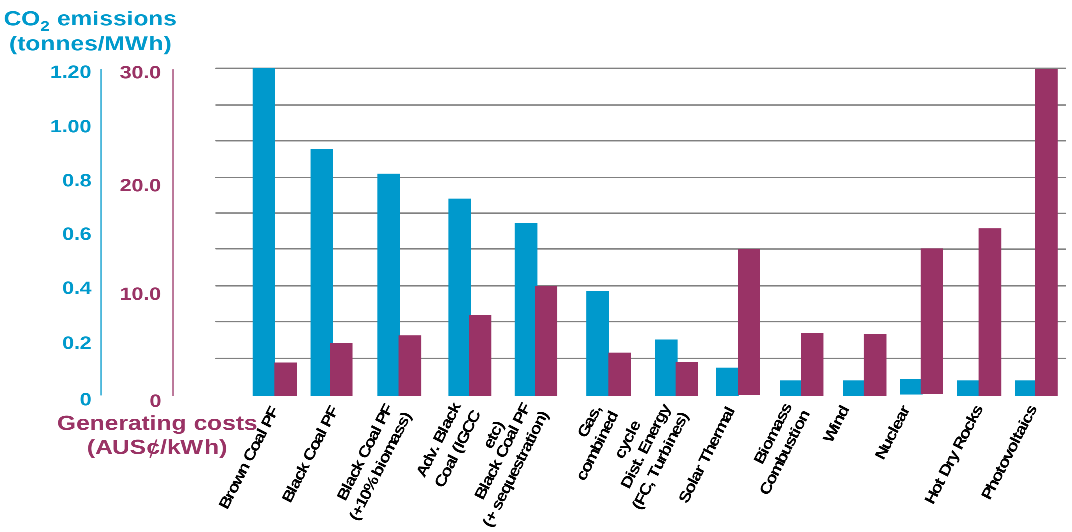

Figure 11. Process generating costs and CO_2 emission comparisons
Source: J Smitham, CSIRO, June 2006

Wind power is now anticipated to grow to a level of at least 20% of total power generation in several countries and, in Western Australia, could assist substantially in meeting the challenge of reducing CO_2 emissions by more than 40 Mt CO_2 to 2030.

POTENTIAL RESEARCH AND TECHNOLOGY OBJECTIVES TO 2030

- Applicable technology outlook across four geographic sectors

Western Australia can be divided into the following four geographic sectors on the basis of geographic circumstances, the diverse energy sources available, the optimum technological options and the customised developments likely to reduce CO_2 emissions in stationary energy: Coastal areas, South-West Interconnected System (SWIS), the North-West Shelf area and Remote regional areas comprising significant population centres, such as Kalgoorlie, together with widely dispersed areas of mining production. Technologies or processes that may be optimally suited to each of these four sectors over the short-term (2006 - 2010), the medium-term (2010 - 2020) and the long-term (between 2020 - 2050) are depicted in the matrix of technology evolution in (Figure 12).

	Immediate-term 2006-2010	Short-term 2010-2020	Long-term 2020-2050
Coastal	Efficiency Wind	Wave and tidal Wind	Wave and tidal Wind
South west interconnected system	Efficiency Natural gas Wind	Geothermal Wave	Solar Gas reforming Geothermal Geosequestration Fuel cells Hydrogen
North-West	Efficiency Natural gas	Geosequestration Wave and tidal Natural gas	Solar Gas reforming Fuel cells Hydrogen
Remote area WA	Biomass Efficiency Wind	Solar Clean coal	Solar Fuel cells Clean coal

Figure 12. Matrix showing the potential introduction of energy process technologies over the short, medium and long-term for the four geographic sectors in Western Australia.
Source: Adapted from B Hobbs, 2005

The processes/technologies relevant to the short-term are available now at the commercial scale in Western Australia. Processes/technologies identified as relevant to the medium-term are currently at prototype or pilot scale development but, through concerted planning and promotion, could be increasingly deployed in Western Australia. The long-term processes/technologies are currently at the exploratory or investigative stage of development and are subject to prolonged learning-curves before serving as competitive energy prospects.

- Generic core technologies for future energy processes

Separation of CO_2 from other gases and nanotechnology

One of the most energy-intensive operations in industrial activity is the separation of materials, and, so it remains in the energy industry; whether it be the current extraction of coal and gas resources or the future separation of carbon dioxide from flue gasses and from natural gas.

Historically, energy reductions in separation operations are invariably associated with improved efficiency. Future improvements in gas separation, particularly within the next 30 years, will be at the core of many future clean energy developments and the higher efficiencies necessary for emissions abatement and the long-term goal of zero emissions.

Future separation technologies will be increasingly founded at the molecular level and will benefit from the greater understanding of molecular processes in arising from the field of nanotechnology. The wide-ranging impact of separation science is illustrated in Figure 13. These include the important areas of energy production and storage. Moreover, separation science will also impact on the future economics of water purification, including critical applications in desalination and water recycling.

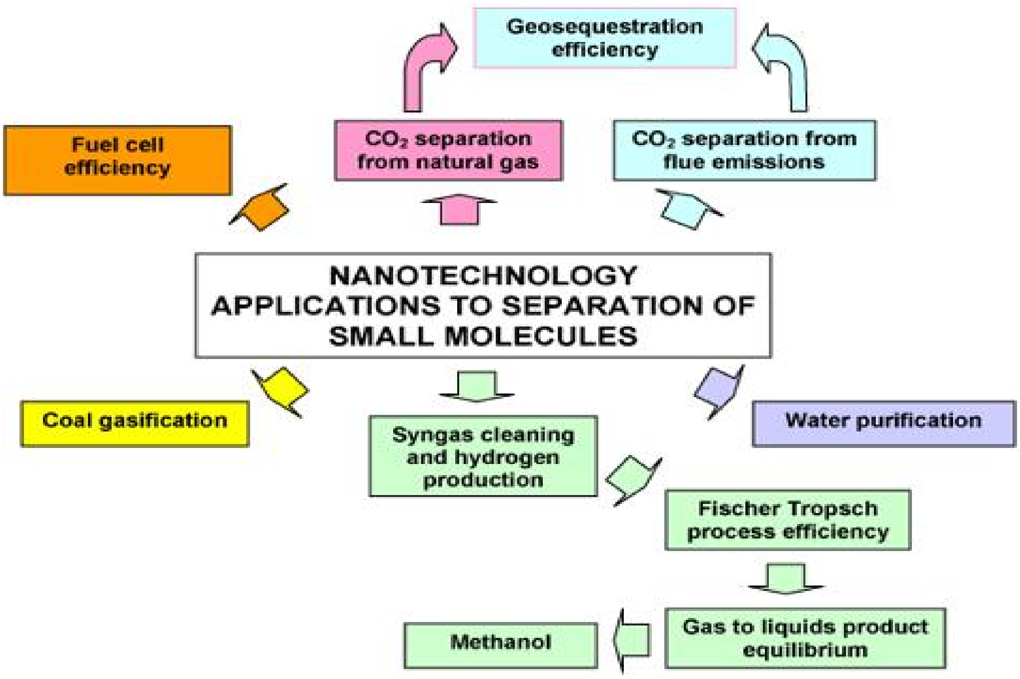

Figure 13. Schematic representation of the wide-ranging impacts of separation science in areas relevant to Western Australia's energy areas.

Yasushi Yoshino et al., including co-author B N Nair from Curtin University, recently described innovations in microporous ceramic membranes for highly selective gas separations.[71] These are silica and alumina composite membranes designed to operate at temperatures between 300-600^{o}C and with specific applications intended to improve hydrogen recovery in equilibrium-limited processes such as steam reforming and integrated gasification combined cycle.

Western Australia is internationally recognised as an economy-of-scale supplier of raw materials for ceramic production and well placed to add value to these industries over the long term. Public support for suitable research capability to the level of international competitiveness in this field of science is, therefore, suggested ahead of potential economy-of-specialisation outcomes in separation technologies.

Recommendation 6.
As part of an Energy Technology Innovation Strategy, prioritise support over 10 years for research and development in nanotechnology initiatives applicable to the efficient separation of gases.

Acknowledgements

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[71] Yoshino Y, Suzuki T, Nair B N, Taguchi, H, Itoh N, "Development of tubular substrates, silica based membranes and membrane modules for hydrogen separation at high temperature", *J. Membane Sci.,* 2005, 267, 8.