Appendices

Assessment of CSIRO Impact & Value

Report prepared as input to
CSIRO's Lapsing Program Review

Prepared for CSIRO

July 2010

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Economics Policy Strategy

A CSIRO functions under its Act

CSIRO is an independent statutory authority, governed by the Science and Industry Research Act 1949, and charged under that Act with the following functions:

a. to carry out scientific research for any of the following purposes:
   - (i) assisting Australian industry;
   - (ii) furthering the interests of the Australian community;
   - (iii) contributing to the achievement of Australian national objectives or the performance of the national and international responsibilities of the Commonwealth;
   - (iv) any other purpose determined by the Minister;

b. to encourage or facilitate the application or utilization of the results of such research;
   - to encourage or facilitate the application or utilisation of the results of any other scientific research;
   - to carry out services, and make available facilities, in relation to science;

The above two are defined as the primary functions. However, the Act also lists the following as secondary functions:

c. to act as a means of liaison between Australia and other countries in matters connected with scientific research;

d. to train, and to assist in the training of, research workers in the field of science and to co-operate with tertiary-education institutions in relation to education in that field;

e. to establish and award fellowships and studentships for research, and to make grants in aid of research, for a purpose referred to in paragraph (a);

f. to recognize associations of persons engaged in industry for the purpose of carrying out industrial scientific research and to co-operate with, and make grants to, such associations;

g. to collect, interpret and disseminate information relating to scientific and technical matters; and

h. to publish scientific and technical reports, periodicals and papers.

B Mapping CSIRO across capabilities, costs and outcomes

The following table sets out an overview of a range of linkages across CSIRO that feed into its collective capability and value. It attempts to assemble a mapping of CSIRO's capabilities, clients/partners, outputs, outcomes and drivers of value to Portfolios, Flagships, Facilities, Collections and Platforms

Portfolio / Flagship / Facility / Collection / Platform	Goals	Themes	CSIRO expenditure* / yr	Supporting Divisions**	Capabilities used**	Clusters / examples of clients and/or partners	Selected outputs and outcomes / impacts	Options created
Agribusiness Group: enhance the global competitiveness and sustainability of agribusiness industries; and improve human well-being and community health by performing world-class and strategic research								
Entomology Portfolio	Integrate diverse biological sciences from the level of the gene to the ecosystem to deliver knowledge for biosecurity and bio-industries	Plant biosecurity and invasive species Building bioindustries with synthetic biology	$26.2m	• Entomology • Plant Industry • Sustainable Ecosystems • Marine and Atmospheric Research • Earth Science and Resource Engineering • Molecular and Health Technologies • Mathematics, Informatics and Statistics	Drawing on 19 capabilities, e.g. Invertebrate genomics and evolution, Invasion biology and functional ecology, Forest and agricultural systems, Marine ecological processes and prediction	• Grains Research and Development Corporation • CRC National Plant Biosecurity • United States Department of Agriculture – Agricultural Research Service • Horticulture Australia Limited • Invasive Animals CRC	• Crazy ant population eradication protocol validated and transferred to affected Aboriginal communities • Biological control plan for weed management transferred to Ecuadorian Government • Artificial intelligence tool for pest management prioritisation transferred to grains industry partners	Option to manage and eradicate invasive species Option to build bio-industries sectors for the Australian manufacturing industries in chemical industry products and environmental services

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Livestock Industries Portfolio	Provide research solutions to increase the total factor productivity of Australia's livestock industries and to protect them against the threat of new and emerging diseases	Transforming animal biosecurity Transforming the animal and its products	$44.8m	• Livestock industries • Molecular and Health Technologies	Drawing on 8 capabilities, e.g. Pathogen identification and characterisation, Diagnostic sciences; Modulation of host responses; Animal genomics and genetic analysis; Animal biology and development; Bioindustry product development; Microbial biology and metagenomics, Livestock, landscape and environmental interactions	• Commonwealth Department of Agriculture, Fisheries and Forestry • Malta Advanced Technologies Ltd • Commonwealth Department of Innovation, Industry, Science and Research • Meat and Livestock Australia Ltd • Beef CRC Ltd • AusAID	• Efficacy of human influenza vaccines improved, providing a pathway for delivery of the first H1N1 pandemic influenza vaccine to the global marketplace • New sheep breeding technologies enable resistance to fly strike and improved animal welfare	Monitor and manage livestock disease outbreaks and particularly exotic diseases. Monitor, manage and treat human diseases which originate in animals: e.g. Hendra Choose cattle or sheep that are better suited to defined environments and markets based on genetic make-up. Choose the most appropriate method for managing ruminants for minimal methane production. Evidence to underpin the development of animal welfare policies and procedures.
Plant Industry Portfolio	Promote profitable and sustainable agrifood, fibre and horticultural industries through innovative change and the development of new plant products	New horizons in plant science Delivering quality crops for consumer choice and improved industry competitiveness Plant fibre and biofactories for new agricultural and industrial products Designing crops and pastures for Australian environmental challenges	$70.2m	• Plant Industry • Materials Science and Engineering • Mathematics and Information Sciences	Drawing on 11 capabilities, e.g. Plant genomics, Cereal crop improvements, Conservation biology and sustainable production systems, Fibre engineering	• Cotton Seed Distributors Ltd • Grains Research and Development Corporation • Grape and Wine Research and Development Corporation • Cotton Catchment Communities CRC • CRC for Sugar Industry Innovation through Biotechnology • Horticulture Australia Ltd • HRZ Wheats Pty Ltd	• Wheat lines with enhanced crown rot resistance transferred to Australian breeding companies • Robustness of information generated by next-generation sequencing approaches improved through novel analysis tool • Cotton fibre measurement instruments commercialised • CSIRO cotton varieties adopted by nearly 100% of the market	Option to develop sustainable agrifood, fibre and horticultural industries Option to improve natural resource management

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Food and Nutritional Sciences Portfolio	Conduct research on food processing, safety and benefit to support the health and well-being of the Australian community and the sustainability and viability of the Australian food industry	Transforming food manufacture Enhancing food benefit and safety	$17.1m	• Food and Nutritional Sciences • Mathematics, Informatics and Statistics	Drawing on 8 capabilities, e.g. Health and sensory science, Food materials science, Food chemistry and biofunctionality, Quantitative biosciences	• Victorian Department of Primary Industries • Meat and Livestock Australia Ltd • Mars Australia Pty Ltd • University of Tasmania • Deutsches Institute fur Lebensmitteltechnik	• Information about Hepatitis A and semi dried tomatoes used by Food Standards Australia New Zealand to develop new standards • Reach 100 knowledge and capability on Genome Health Clinic operations transferred to Gachon Gil Hospital in Seoul	Option to improve the sustainability and viability of the Australian food industry Option to bring about health and wellbeing benefits for the Australian community

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Food Futures Flagship	Transform the international competitiveness of, and add $3 billion annually to, the Australian agrifood sector by the application of frontier technologies to high-potential industries	Future grains, grain-based food and feed Breed engineering Designed food and ingredients Quality biosensors	$49.2m	• Entomology • Livestock Industries • Plant Industry • Food and Nutritional Sciences • Sustainable Ecosystems • Marine and Atmospheric Research • Materials Science and Engineering • Molecular and Health Technologies • ICT • Mathematical and Information Sciences	Drawing on 34 capabilities, e.g. Enzymology and synthetic biology, Animal genomics and genetic analysis, Bioindustry product development, Plant metabolic engineering, Food materials science, Food microbiology and safety	• High Fibre Grains Cluster • Concentration and Separation of Bioactives in Food Science Cluster • Olfactory Pattern Recognition Cluster • Healthy Complex Cereal Carbohydrates Cluster (first round Cluster almost completed and 2nd still being setup) • Sex Ratio and Sterility for Commercial Animal Production Cluster (still being setup) • Grains Research and Development Corporation • Arista Cereal Technologies Pty Ltd • AQ1 Systems Pty Ltd • Australian Centre for International Agricultural Research • Seafood CRC Company Ltd • Centre for Grain Food innovation (Curtin University of Technology and DAFWA)DAFWA / Murdoch wheat quality CRC • Bayer (wheat transformation and wheat genetic platforms	• BARLEYmax commercialised and work on WHEATmax underway • Demonstrated production of Omega 3 in plants • Aquaculture prawn breeding and novel feed creating high yields using carbon waste • Next generation, highly selectable, advanced separation technology molecular imprinted polymers developed • Technology to improve pasteurisation of fruit juices and food products used commercially in Melbourne food processing facility • Biosensors (note this may also be an example of a loop back to "Maintain and develop capability and capacity" • Demonstrated testis cell transfer in sheep and cattle(underway. • Improved prawn breeds successfully commercialised.	Improved health outcomes for Australia based on a whole of chain approach (farm to fork) "Feed the world" Improved farm profitability Capability/capacity improvements in food production Alternative foods for people with allergies Information to the wheat breeding community for targeting wheat quality outcomes Sustainable and alternative production of fish oils (land based crop production alternative) Carbon mitigation Options for increasing the rate of genetic improvement amongst extensive cattle herds. Evidence to underpin the development of animal welfare policies and procedures.

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Preventative Health Flagship	Improve the health and wellbeing of Australians and save $2 billion in annual direct health costs by 2020 through the prevention and early detection of disease	Colorectal cancer and gut health Neurodegenerative disease, mental disorder and brain health Obesity and health	$42.4m	• Livestock Industries • Food and Nutritional Sciences • Materials Science and Engineering • Molecular and Health Technologies • ICT • Mathematics, Informatics and Statistics	Drawing on 19 capabilities, e.g. Quantitative biosciences, Information engineering, Molecular and cell biology, Nutrigenomics, Food chemistry and biofunctionality, Statistics	• Stroke Imaging Prevention and Treatment Cluster • ASPREE Healthy Aging Cohort Biobank Cluster • Australian Imaging Biomarker and Lifestyle (AIBL) Cluster • Clinical Genomics Pty Ltd • Pfizer Inc • Ludwig Institute for Cancer Research Switzerland • Clover Corporation Ltd	• Five year bowel cancer survival rate likely doubled due to adoption of advisory letter from National Bowel Cancer Screening Program • Colonoscopy simulator technology licensed	Creating synergies across specialised disciplines to create new research opportunities Creating partnerships that facilitate quick path to market Creating potential for Australian industrial development in novel preventative foods and diagnostic tools
Sustainable Agriculture Flagship	Secure Australian agriculture and forest industries by increasing productivity by 50% and reducing carbon emissions intensity by at least 50% between now and 2030.	Greenhouse gas abatement and carbon storage in land use systems Advancing agricultural productivity and environmental health Landscape systems and trends Partnering for international food and fibre security	$69.0m	• Entomology • Livestock Industries • Plant Industry • Land and Water • Sustainable Ecosystems • Marine and Atmospheric Research • Materials Science and Engineering • ICTC • Mathematics, Informatics & Statistics • Earth Science and Resource Engineering	Drawing on 26 capabilities, e.g. Livestock and environmental systems, Conservation biology and sustainable production systems, Soil and landscape science, Social and economic sciences, spatio-temporal modelling	• Grains Research and Development Corporation • Commonwealth Department of Agriculture, Fisheries and Forestry • Australian Centre for International Agricultural Research • Commonwealth Department of Climate Change and Energy Efficiency • AusAID	• APSIM and similar models used to inform land use decisions • Satellite and SMS Irrigation Scheduling Service adopted and in use • Forest management plan for Vietnamese villagers developed and transferred • Biochar Research – maintaining portfolio capability/knowledge leading to CSIRO being “ready” to undertake major projects to address a national priority i.e. mitigation of greenhouse gases • Flagship is very young many other outcomes are likely to be restricted to creating partnerships etc	Increasing the probability of the science community finding ways of measuring or verifying stored carbon Options to mitigate carbon Options to improve agricultural productivity Options to improve the environment’s health Options to improve the sustainability of landscape systems

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Australian Animal Health Laboratory (within Livestock Industries Division)	Enhance the international competitiveness of Australia's animal industries, the well-being of Australians and the quality of their environment through being a national centre of excellence in disease diagnosis, research and policy advice in animal health	Diagnosis, Surveillance and Response Transforming Animal Biosecurity	$53.0m	• Livestock Industries	Pathogen identification and characterisation Emergency disease preparedness Modulation of host responses Bio-industry product development Animal biology and development	• Commonwealth Department of Agriculture, Fisheries and Forestry • Commonwealth Department of Innovation, Industry, Science and Research • AusAID • Food and Agriculture Organisation • World Health Organisation • World Organisation for Animal Health (OIE) • Pfizer	• Hendra virus discovered and diagnostic tests developed • Expert biosafety and biosecurity advice provided to national and international stakeholders • National surveillance and quarantine processes improved • Vaxxitek vaccine, Fowlpox #2 vaccine, Bovigam test, QuantiFERON test, ILT A20 vaccine, ELISA tests and Bovilis MH vaccine successfully commercialised • Efficacy of human influenza vaccines improved, providing a pathway for delivery of the first H1N1 pandemic influenza vaccine to the global marketplace • Diagnosis, containment and eradication of Equine Influenza	Maintained capability to quickly diagnose exotic and emerging animal diseases, and develop vaccines and treatments Diagnostic Emergency Response Laboratory enables faster processing of more samples World class biocontainment facility enables research into most infectious agents known Monitor, manage and treat human diseases which originate in animals: e.g. Hendra
Australian National Insect Collection (within Entomology Division)	Collect, document and deliver information about Australia's invertebrate fauna	NA	$1.85m	• Divisions that utilise the ANIC include Entomology and Sustainable Ecosystems among others • Portfolios that utilise the ANIC include Entomology, Food Futures and Sustainable Agriculture among others	ANIC is classified as a capability	• Commonwealth Department of Agriculture, Fisheries and Forestry • Grains Research and Development Corporation • National Science Foundation • Chinese Academy of Sciences	• Immediate, real-time identifications provided through the Remote Microscope Network • Research and real-time remote diagnostics to support biodiversity and sustainable agriculture accelerated through the Virtual Taxonomy Laboratory • Australian biosecurity supported through urgent insect identifications	Option to undertake research in evolutionary biology, taxonomy, natural resource management, understanding ecosystems and biodiversity, quarantine decisions and bio-geographic studies

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Australian National Herbarium (within Plant Industry Division) unincorporated joint venture with Director of National Parks and expenditure only reflects CSIRO's expenditure	Undertake and support research by documenting the diversity of the Australian flora through the collation, maintenance and dissemination of herbarium specimens and associated data.	NA		• Divisions that utilise the ANH include Sustainable Ecosystems, Land and Water and Plant Industries among others • Portfolios that utilise the ANH include Plant Industries, Food Futures and Sustainable Agriculture among others	Taxonomic, systematic and phylogenetic research skills, plant nomenclature, spatial data analysis, data management, training/education	• Commonwealth Department of the Environment, Water, Heritage and the Arts	• Extensive collections of readily available, distributed data on the names, identity and spatial and temporal occurrence of the Australian and related floras kept • Taxonomic revisions, floras, electronic identification keys, databases, public outreach activities, training and volunteer programs, and extensive collaborations with other parts of CSIRO and other government and non-government agencies nationally and internationally delivered	Options to undertake additional research on systematics, taxonomy, conservation biology, land management, bioprospecting, evolutionary ecology, molecular phylogenetics
Transformational Biology Capability Platform	Catalyse a step-change in biological capabilities by combining human, plant, and animal biology with genomics, phenomics and whole-of-system approaches	NA	$8.04m	TCP's can fund their own projects drawing on staff from across CSIRO. They can also fund projects, in whole or part, in Divisional Capability Development Funds and Themes. Consequently the mix of Divisional staff contributing to a TCP changes regularly. Some examples might include: • Mathematics, Informatics & Statistics • Plant Industry • Livestock Industries • Entomology	A range of biological and mathematical capabilities	• Main recipient of outputs is CSIRO Portfolios, for example, Preventative Health, Food Futures, Wealth from Oceans, Water for a Healthy Country • European Molecular Biology Laboratory • Broad Institute • J. Craig Venter Institute • International Human Microbiome Consortium • Queensland Institute of Medical Research	• Enhanced skills, expertise and know-how • Research infrastructure • Research relationships	Capability to underpin mechanistic understanding or predictive models of complex biological processes

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Energy Group: aims to develop and apply leading-edge energy research that meets Australian needs								
Energy Transformed Flagship	Identify Australia's pathways to reduce Greenhouse Gas Emissions3 by 25% by 2020 and 90% by 20501 and Develop cost competitive, alternative stationary energy and transport fuels2 solutions that will contribute 50 Mt CO2e to Australia's abatement task	• Carbon futures • Sustainable stationary energy and transport • Local energy technologies	$36m	• Entomology • Food and Nutritional Sciences • Land and Water • Sustainable Ecosystems • Marine and Atmospheric Research • Energy Technology • Earth Science and Resource Engineering • Process Science and Engineering • Materials Science and Engineering • Molecular and Health Technologies • ICT • Mathematics, Informatics and Statistics	• The ETFS draws on 38 capabilities from across CSIRO, e.g. Enzymology and synthetic biology, Genomics, Forest and agricultural systems, Urban science, engineering and technology, Atmospheric and land observation assessment, Petroleum engineering, Fluid dynamics • Around 50% of FTE comes from Energy Technology Division. • Remaining 50% comes from other disciplines, including social) • Increasingly relying on inputs from CSIRO non-energy capabilities	• National Hydrogen Materials Alliance Cluster (*completed*) • Intelligent Grid Cluster (*ongoing*) • Biological Solutions for Energy and Greenhouse Challenges Cluster (still being setup; will include international partners for first time) • Working to develop the Australian Integrated Carbon Assessment System (AICAS) with other related Flagships • Commonwealth Department of Resources, Energy and Tourism • Commonwealth Department of the Environment, Water, Heritage and the Arts • International Power (Technologies) Ltd • Chevron Corporation • Commonwealth Department of Defence	• Brought together Australian research on Hydrogen through the Hydrogen Cluster (while Flagship Collaboration Fund support has ended, activities are continuing through the "Australian Hydrogen Institute") • UltraBattery commercialised with potential to be used to address stationary energy and transport carbon reduction technologies • Technology to mitigate CO_2 emissions through intelligent control of HVAC systems commercialised and start-up company established • Intelligent Grid report published contributing to new partnerships and debate about the value of distributed energy and potential policy options	Increasing the probability of the science community finding ways of mitigating of climate change through worldwide reduction of emissions from transport and energy generation Creation of mitigation options which are suitable for Australian conditions Creating options for a more seamless introduction of climate change mitigation and adaptation technologies (e.g via the proposed AICAS)

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Wealth from Oceans Flagship	Position Australia by 2020 as an international benchmark in the delivery of economic, social and environmental wealth based on leadership in the understanding ocean systems and processes	The dynamic ocean: building foundations for climate, national security and sustainable marine industries Our resilient coastal Australia Sustainable ocean ecosystems and living resources	$80.3m	• Entomology • Food and Nutritional Sciences • Land and Water • Sustainable Ecosystems • Marine and Atmospheric Research • Earth Science and Resource Engineering • Materials Science and Engineering • Molecular and Health Technologies • ICT • Mathematics, Informatics and Statistics	• The WfO FS draws on 41 capabilities from across CSIRO, e.g. Social and economic sciences, Marine ecological processes and prediction, Earth system modelling, Petroleum geoscience, Wave physics • The Earth Science and Resource Engineering and Marine and Atmospheric Research Divisions each provide around a third of FTE. • Remainder comes from a range of other disciplines.	• Ningaloo Collaboration Cluster • Subsea Pipeline Collaboration Cluster • The Enabling Science Uptake in Australia's Coastal Zone Collaboration Cluster (The Coastal Cluster); with CAF • Western Australian Alliance for Advanced Energy Solutions (alliance with Chevron and ERA) • The Australian Resources Research Centre • Sensor systems for analysis of aquatic environments (with Future Manufacturing and WFHC Flagships) • Commonwealth Department of Agriculture, Fisheries and Forestry • Western Australian Marine Science Institution • Fisheries Research and Development Corporation • AusAID	• Australia's Northern Prawn Fishery declared a 'global model' for sustainable fisheries management – ABARE estimate 43% increase in profitability – Also social and environmental outcomes • 274 new marine species and 80 undersea mountains discovered • Models developed to help reduce oil and gas exploration risk and optimise well placement • First map of Australia's undersea mineral deposits created • Ocean modelling and analysis capability developed enabling production of accurate forecasts of ocean conditions in the Australian region for the first time	Improve sustainability of prawn fisheries world wide Increase efficiency and productivity of gas exploration Increase probability of finding mineral resources in the ocean
Coal Technology Portfolio	Maximise the benefits from Australia's coal resources in an environmentally and socially responsible manner	Coal production Coal utilisation Carbon dioxide capture and geological storage	$11.9m	• Earth Science and Resource Engineering • Process Science and Engineering	Examples include Earth system modelling, Petroleum geoscience	• Commonwealth Department of Resources, Energy and Tourism • Australian Coal Research Ltd • UCC Energy Ptd Ltd • Tarong Energy Corporation Ltd • Huainan Coal Mining Group Co Ltd	• Handbook on impact of saline water on coal cleaning plants produced and distributed • Respirable dust levels in longwall mines reduced through development of new shearer scrubber system • Ultra Clean Coal processing improved to reduce production energy costs and improve product quality	Option to reduce GHG emissions through efficient and low emission coal technologies Option to generate energy more efficiently

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Petroleum & Geothermal Portfolio	Support a smooth transition to Australia's clean and secure energy future by optimising oil and gas exploration and production, and demonstrating the feasibility of geothermal energy use in Australia	Unconventional petroleum and geothermal resources Conventional petroleum exploration and production	$16.7m	• Earth Science and Resource Engineering • Process Science and Engineering	Examples include Earth system modelling, Petroleum geoscience	• Petronas Research • Chevron Corporation • Australian Research Council • Geodynamics Ltd • Aramco Overseas Company	• Petroleum hydrogeology services provided to help solve exploration and development challenges such as water resources and management	Option to transition Australia to a clean and secure energy future

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Environment Group: aims to support the development of production sectors while at the same time minimising current and potential adverse environmental impacts								
Marine and Atmospheric Research Portfolio	Provide the earth-system science that creates new knowledge of Australia's climate, supports adaptation responses to increasing climate change and variability, and advises on mitigation strategies	Climate and atmosphere	$28.4m	• Land and Water • Sustainable Ecosystems • Marine and Atmospheric Research	Drawing on 9 capabilities, e.g. Water reuse, Atmospheric and land observation assessment, Earth system modelling, Weather and environment prediction	• Commonwealth Department of Climate Change and Energy Efficiency • University of Queensland • University of Tasmania • AusAID • Commonwealth Department of Innovation, Industry, Science and Research	• Software created to improve location and building of wind farms • Spin off company, Windlab, established in 2003 • Australian Water Availability Project used to populate the first National Water Accounts	Increasing the probability of wind farms being able to maximise the capacity factor and thus increase their potential to contribute to low carbon energy generation
Biodiversity Portfolio	Provide the data, tools and integrating knowledge to underpin a collective national effort to help halt biodiversity decline in Australia by 2020 and reverse this decline by 2035	Building resilient Australian biodiversity assets	$27.5m	• Entomology • Plant Industry • Sustainable Ecosystems • Marine and Atmospheric Research	Drawing on 10 capabilities, e.g. Conservation biology and sustainable production systems, Systematics, collections and information management, Social and economic sciences	• Commonwealth Department of Innovation, Industry, Science and Research • Commonwealth Department of the Environment, Water, Heritage and the Arts • Roads and Traffic Authority of New South Wales • AusAID • Commonwealth Department of Agriculture, Fisheries and Forestry	• Review of metrics for biodiversity conservation findings adopted • Virtual Taxonomic Laboratory launched	Option to preserve and restore Australia's biodiversity

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Water for a Healthy Country Flagship	Provide Australia with solutions for water resources management, creating economic gains of $3 billion a year by 2030, while protecting or restoring the country's major water ecosystems	Urban water Integrated water information systems Healthy water ecosystems Regional water	$99.0m	• Entomology • Livestock Industries • Plant Industry • Land and Water • Sustainable Ecosystems • Marine and Atmospheric Research • Earth Science and Resource Engineering • Process Science and Engineering • Materials Science and Engineering • Molecular and Health Technologies • ICT • Mathematics, Informatics and Statistics	Drawing on 36 Capabilities, e.g. Invasion biology and functional ecology, Environmental and information systems, Groundwater hydrology, Catchment biogeochemistry and aquatic ecology, Social and economic sciences, Integrated nanoscience	• Coorong, Lower Lakes and Murray Mouth ecology Cluster • Advanced Membrane Technologies for Water Treatment Cluster • Environmental Water Cluster (still being setup) • Sensor systems for analysis of aquatic environments (with Future Manufacturing and Wealth From Oceans Flagships) • Commonwealth Department of the Environment, Water, Heritage and the Arts • National Water Commission • Urban Water Security Research Alliance Trust • Commonwealth Department of Climate Change and Energy Efficiency • Water Corporation (WA) • Melbourne Water (Vic) • Murray-Darling Basin Authority • Australian Bureau of Meteorology (BoM) • Water Information Research and Development Alliance (with BoM) • Goyder Institute (South Australia) • eWater CRC • Murray Darling Freshwater Research Centre	• World's largest basin scale investigation of the impacts of catchment development, changing groundwater extraction, climate variability and climate change on water resources undertaken • Irrigation systems efficiency assessment (Hotspots) methodology • National guidelines for 1) recycled water from managed aquifer recharge developed; 2) drinking water quality • Advances in pathogen detection and modelling, the design and performance of managed aquifer recharge • Options for Melbourne water supply highlight nexus between energy and water under scenarios of climate change • Steam recovery technology with industrial application to recover water • Developed accurate measurements of the sediment and nutrient loads from Great Barrier Reef catchments • Experimental seasonal streamflow forecasting with acceptable level of predictive skill • Water data transfer format adopted by the water industry and on the path an international standard	Option to improve the sustainability of the Murray Darling Basin Options to target sustainable irrigation system modernisation Options to improve the sustainability in Northern Australia, Tasmania and south-west Western Australia. Options to improve environmental and human health and safety Options for optimising water supply augmentation under scenarios of climate change Options for recovery and reuse of water, nutrients and energy from wastewater (e.g. stormwater) Options for reducing nutrients and sediments to the GBR Options for improved water allocation and water use decisions Options enabling near real time access and exchange of water data and information A 2009 Deloitte review estimated that "Flagship research can reasonably be expected to contribute to, influence or direct decisions relating to current and planned investment worth a total of $11.52 billion. In order to exceed the level of investment in the Flagship, the efficiency gains due to its research would only need to be 2.2 per cent".

Portfolio / Flagship / Facility / Collection / Platform	Goals	Themes	CSIRO expenditure* / yr	Supporting Divisions**	Capabilities used**	Clusters / examples of clients and/or partners	Selected outputs and outcomes / impacts	Options created
Climate Adaptation Flagship	Equip Australia with practical and effective adaptation options to climate change and variability, and in doing so create $3 billion a year in net benefits by 2030	Pathways to adoption Sustainable cities and coasts Managing species and natural ecosystems Adaptive primary industries, enterprises and communities	$42.5m	• Sustainable Ecosystems • Marine and Atmospheric Research • Entomology • Plant Industry • Land and water • Earth Science and Resource Engineering • ICT • Mathematical and Information Sciences • Materials Science and Engineering	Drawing on 28 capabilities, e.g. Plant genomics, Forest and agricultural systems, Social and economic sciences, Urban science, engineering and technology, Climate variability and change including extreme events, Environmental informatics; Bushfire behaviour, Marine impacts	• Climate Adaptation in South East Queensland Cluster • Urbanism, Climate Adaptation and Health Cluster • The Enabling Science Uptake in Australia's Coastal Zone Collaboration Cluster (The Coastal Cluster); with WfO • Australian Centre for International Agricultural Research • Commonwealth Department of Agriculture, Fisheries and Forestry • Commonwealth Department of Climate Change and Energy Efficiency • Bushfire CRC Ltd • Queensland Department of Employment, Economic Development and Innovation	• 'Adapting Australian primary industries to climate change' published and second print run required to meet demand • Evidence to the 2009Royal Commission into the Victorian Bushfires and knowledge on rebuilding fire-damaged communities provided • Climate Change in Australia report (2007) widely used • Western Port adaptation study and Sydney Coastal Council study supports local decision making	Consideration of the whole lifecycle. i.e. GCM development, climate projections, sectoral analysis of impacts, social and economic dimensions of adaptation Innovative options in urban planning and engineering to improve climate adaptation and sustainability outcomes in our cities and coasts Options for planning and management to build resilience in our ecosystems and technologies to facilitate species adaptation New technologies to help farmers adapt their current management systems and transformational options for policy and industries to structurally adjust to climate change and variability

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Marine National Facility (within Marine and Atmospheric Research Division)	Support research by the marine science community across Australia's ocean territory and adjoining oceans by acquiring data for research in oceanography, climatology, marine ecosystems, fisheries and geosciences	Marine National Facility	$14.0m	• Divisions that utilise the MNF include Marine and Atmospheric Research • Portfolios that utilise the MNF include Wealth from Oceans	Examples include Marine ecological processes and prediction, Earth system modelling, Petroleum geoscience, Wave physics	• Geoscience Australia • University of New South Wales • Australian National University • University of Tasmania • University of Western Australia • University of Sydney • Australian Institute of Marine Science • South Australian Research and Development Institute	• Changes in the ocean environment accurately and rapidly detected and predicted • Coastal ecosystems and living resources monitored • Marine geology surrounding Australia investigated and assessed	Enhances Australia's capability for oceanographic, geoscientific, fishery and ecosystem research
Australian National Wildlife Collection (within Sustainable Ecosystems Division)	Support research into understanding the evolutionary history of the terrestrial vertebrate fauna of Australia through systematics, biogeography and population genetics	NA	$650,000	• Divisions that utilise the ANWC include Sustainable Ecosystems • Portfolios that utilise the ANWC include Climate Adaptation • The ANWC is part of the Transformational Biology TCP	Examples include Systematics, Biogeography and Population genetics	• South Australian Museum • University of Adelaide • Australian National University • University of Queensland • Griffith University • Commonwealth Department of the Environment, Water, Heritage and the Arts • Mining companies, indigenous communities • Genome 10K	• New goanna species identified • Regional species populations documented • Conservation priority advice provided to underpin the formation of Kakadu National Park and World Heritage Area and Shoalwater Bay Conservation Reserve • *Directory of Australian Birds* and *Boom and Bust – Bird Stories for a Dry Country* published	Records and data for research involving traditional museum specimens and digitally stored sound files Records and data to enable research into conservation and understanding of Australia's evolutionary diversity

Portfolio / Flagship / Facility / Collection / Platform	Goals	Themes	CSIRO expenditure* / yr	Supporting Divisions**	Capabilities used**	Clusters / examples of clients and/or partners	Selected outputs and outcomes / impacts	Options created
Australian National Fish Collection (within Marine and Atmospheric Research Division)	Provide the fundamental capability and support to underpin scientific research on Australia's marine biodiversity, ensuring the economically and ecologically sustainable use of our marine habitats, fishes and seafood resources	NA	$473,000	• Divisions that utilise the ANFC include Marine and Atmospheric Research • Portfolios that utilise the ANFC include Wealth from Oceans	Examples include Marine ecological processes and prediction, Catchment biogeochemistry and aquatic ecology	• Commonwealth Department of the Environment, Water, Heritage and the Arts • Fisheries Research and Development Corporation • Australian Fisheries Management Authority • National Science Foundation (USA) • Atlas of Living Australia • Australia Museum • Consortium for the Barcode of Life	• Collection of 145,000 finfish specimens maintained and recorded • Data provided for scientific publications including *Sharks and Rays of Australia* • Data provided to the Regional Marine Planning process • Historical datasets provided to underpin climate change research	Option to undertake research in marine biology and conservation of aquatic biodiversity
Australian National Algae Culture Collection (within Marine and Atmospheric Research Division)	Maintain the sole collection of living microalgal diversity in the southern hemisphere to underpin biodiversity characterisation and research	NA	$464,000	• Divisions that utilise the NACC include Marine and Atmospheric Research, Plant Industry, and Land and Water • Portfolios that utilise the NACC include Wealth from Oceans, Energy Transformed, Water for a Healthy Country and Food Futures	Examples include Quantitative biosciences, Information engineering, Molecular and cell biology	• Atlas of Living Australia • Canadian Barcode of Life • Supply more than 50 countries globally with microalgae	• 1000 strains of Australia's microalgal biodiversity maintained for CSIRO and researchers, industry and educationalists nationally and internationally • Records of new acquisitions and strain characterisation continuously updated	Option for research on halting biodiversity decline, the potential for producing biodiesel from algae, the mitigation of CO2 and other GHGs, the potential for sustainable production of omega-2 oils with human health benefits, and improving biogeochemical models and aiding environmental management

Portfolio / Flagship / Facility / Collection / Platform	Goals	Themes	CSIRO expenditure* / yr	Supporting Divisions**	Capabilities used**	Clusters / examples of clients and/or partners	Selected outputs and outcomes / impacts	Options created
National Soil Archive (within Land and Water Division)	Provide facilities and protocols for conserving the long-term scientific value of soil specimens and associated soil data, and to make these specimens and their data available for public research, both now and into the future	NA	$150,000	• Divisions that utilise the NSA include Land and Water and Plant Industry • Portfolios that utilise the NSA include Sustainable Agriculture and Water for a Healthy Country	Examples include Conservation biology and sustainable production systems, Soil and landscape science	• Commonwealth Department of Agriculture, Fisheries and Forestry • Australian Collaborative Land Evaluation Program	• Archive facility, collection and protocols established and maintained • Soil carbon sequestration and soil monitoring research supported, particularly through availability of baseline soil condition information • Data provided for assessments of the sustainability of Australia's food production • Archive provided for some State agencies	Option to assess temporal changes in soil properties in the future
Information Sciences Group: houses the core of CSIRO's research in astronomy, mathematical services and information and communication technologies								
Radio Astronomy Portfolio	Further the advancement of knowledge and understanding of the universe, ensure the continuing world-class nature of the Australia Telescope, and exploit its unique southern location and technological advantages	Technologies for radio astronomy Astrophysics	$8.9m	• Astronomy and Space Sciences	Drawing on 3 capabilities	• Astronomy Australia Ltd • National Aeronautics and Space Agency • University of Sydney • Australian Research Council	• Receiving systems, signal processing, data transfer and recording, and specialised software for radio astronomy developed	Option for Australia to house the Square Kilometre Array Capability in radioastronomy technology development Option to provide further understanding about the universe

Portfolio / Flagship / Facility / Collection / Platform	Goals	Themes	CSIRO expenditure* / yr	Supporting Divisions**	Capabilities used**	Clusters / examples of clients and/or partners	Selected outputs and outcomes / impacts	Options created
Digital Technologies and Services Portfolio	Provide the digital technologies and services that underpin national efforts in the delivery of globally competitive outcomes for society, government and industry	eHealth Broadband wireless for connecting Australia Services oriented systems	$27.3m	• Sustainable Ecosystems • Materials Science and Engineering • ICT • Mathematics, Informatics and Statistics	Drawing on 10 capabilities, e.g. Social and economic sciences, Information engineering, Wireless technologies, eHealth, Business and service analytics, Computational and mathematical modelling	• Commonwealth Service Delivery Agency (Centrelink) • Fenics/GFI Group • Commonwealth Department of Defence • Australian Centre for Advanced Computing and Communication Pty Ltd	• Research alliance with Centrelink formed • Research conducted for service companies such as Hunter Valley Coal Chain, GFI-Fenics, Opal Productions of Australia Ltd and Britz-Maui	Option to improve delivery and reduce costs in the provision of services
Australian Square Kilometre Array Pathfinder Portfolio	Maximise returns to Australian science and industry through participation in the international Square Kilometre Array (SKA) project and development of the Australian SKA Pathfinder (ASKAP)	The Australian SKA Pathfinder	$9.2m	• Astronomy and Space Sciences • ICT	Drawing on 3 capabilities, i.e. Networking technologies, Wireless technologies, Radio science and engineering	• University of Western Australia • Herzberg Institute of Astrophysics • ASTRON • Max Planck Institute • Auckland University of Technology	• New technologies for the international Square Kilometre Array telescope demonstrated	CSIRO has worked with other stakeholders to increase the probability that Australia will be chosen as the preferred site

Portfolio / Flagship / Facility / Collection / Platform	Goals	Themes	CSIRO expenditure* / yr	Supporting Divisions**	Capabilities used**	Clusters / examples of clients and/or partners	Selected outputs and outcomes / impacts	Options created
Computational Simulation Science Transformational Capability Platform	Enable step-change growth in computational capabilities to accelerate the delivery of next-generation applications for industry and the community	NA	$6.34m	TCP's can fund their own projects drawing on staff from across CSIRO. They can also fund projects, in whole or part, in Divisional Capability Development Funds and Themes. Consequently the mix of Divisional staff contributing to a TCP changes regularly. Some examples might include: • Mathematics, Informatics & Statistics • Materials Science and Engineering • Marine and Atmospheric Research • Land and Water • ICT	Platform supports capability development across the organisation. Examples of capability development include material science, imaging and visualisation, environmental monitoring and modelling, molecular design, advanced collaboration, bioinformatics, and many other areas of computational and simulation science	• Main recipient of outputs is CSIRO, for example the platform contributes directly to the Wealth from Oceans, Future Manufacturing, Light Metals and Preventative Health Flagships • The Platform develops capability in nearly all CSIRO divisions • The CSS TCP actively partners with the other CSIRO platforms to support capability development in advanced materials, bioinformatics, and sensor and sensor networks • The CSS TCP currently partners with Australian Synchrotron, ANU, VeRSi, VPAC and NeAT to develop advanced CT reconstruction services to support medical and advanced materials research. • The CSS TCP is currently developing advanced collaboration tools and technology with the Australian Animal Health Laboratory	• Leading edge technology provided through world class computational resource (CSIRO GPU cluster) to support computational and simulation science research across CSIRO • Advanced visualisation tools, an imaging and image analysis service, and high end visualisation and collaboration tools such as the Optiportal technology provided • Advanced collaboration tools delivered to the Australian Animal Health Laboratory to support emergency response • Annual conference and workshops with hundreds of participants organised and run	Option to accelerate delivery of Flagship goals Option to accelerate state-of-the-art research in materials science, imaging and image analysis, visualisation, biology, advanced collaboration and high performance computing technologies Option to build new world class strategic facilities and capabilities in computational science Option to support NBN through advanced collaboration tools and technologies

Portfolio / Flagship / Facility / Collection / Platform	Goals	Themes	CSIRO expenditure* / yr	Supporting Divisions**	Capabilities used**	Clusters / examples of clients and/or partners	Selected outputs and outcomes / impacts	Options created
Sensors and Sensor Networks Transformational Capability Platform	Create sensor network technologies that will transform our understanding and management of the environment and resources which underpin Australia's way of life by providing a transformational data driven approach to scientific discovery	NA	$10.7m	TCP's can fund their own projects drawing on staff from across CSIRO. They can also fund projects, in whole or part, in Divisional Capability Development Funds and Themes. Consequently the mix of Divisional staff contributing to a TCP changes regularly. Some examples might include: • Mathematics, Informatics & Statistics • Materials Science and Engineering • ICT • Energy Technologies • Land and Water	Information engineering, Data privacy and security, Wireless technologies, Material Science, Device and Systems Engineering, Analysing complex data and events, Energy harvesting Signal processing, Information Theory, Computer Vision, Data Fusion Automated systems, Livestock science, Environmental sensing, Water Science and Engineering	• Main recipient of outputs is CSIRO, for example the platform contributes directly to the Wealth from Oceans, Water for a Healthy Country, Future Manufacturing and Sustainable Agriculture Flagships • The Australian Rainforest Conservation Society • QLD Department of Environment and Resource Management • Seqwater (Bulk water supply provider) • Royal Australian Mint • The Powercom Group (TAS, remote monitoring systems) • Procept (VIC, embedded products) • Stanford University, USA • University Saarbrücken, Germany • Kyushu University, Japan • Umea University, Sweden • Australian Research Collaboration Service (informal)Melbourne Centre for Nanofabrication • World Wide Web Consortium (W3C)	• World's first communication protocol that operates on 2.4GHz and 900MHz with antenna diversity to achieve high link reliability and spectrum agility for sensor nodes developed • Semantic sensor webs through the W3C Semantic Sensor Networks incubator group (SSN-XG) standardised • System to track restoration of a rainforest and to provide insights into how microclimates and biodiversity change over time (deployed at Springbrook, QLD) developed • Longest running catchment scale water quality monitoring network (with Seqwater) developed • World's first in-rumen wireless H2, CO2, and CH4 concentration sensing (e.g. for selective breeding towards low GHG emissions) developed • Low cost flow through UV254 sensor for sensing organic contamination in water at sub-ppm levels developed • Low cost composite material for use in a sensing electrode for monitoring water quality (World Patent) developed	Capability to underpin research at scientific frontiers requiring real-time data feeds, advanced data processing and distributed information extraction

Portfolio / Flagship / Facility / Collection / Platform	Goals	Themes	CSIRO expenditure* / yr	Supporting Divisions**	Capabilities used**	Clusters / examples of clients and/or partners	Selected outputs and outcomes / impacts	Options created
Australia Telescope National Facility (within Astronomy and Space Science Division)	Operate the most productive radio astronomy facility in the southern hemisphere in order to serve the Australian and international scientific community	Australia Telescope National Facility Operations	$12.5m	• Portfolios that utilise the ATNF include Radio Astronomy and Australian Square Kilometre Array Pathfinder	Examples include Radio telescope operations, Radio science and engineering, Astronomy and astrophysics	• Curtin University • University of Western Australia • Macquarie University • James Cook University • NRC-Canada • ASTRON-Netherlands • SKADS-EU • Max Planck Institute for Radioastronomy • NAOC-China	• World class radio telescope facilities provided at Narrabri, Parkes and Coonabarabran • Receivers tailor-made for ATNF and other telescopes around the world • High speed signal processing systems designed and built	Options for continued world class astronomy research providing further understanding about the solar system and beyond
Canberra Deep Space Communication Complex (within Astronomy and Space Science Division)	Provide mission critical support to spacecraft exploring the solar system as part of the NASA Deep Space Network	Canberra Deep Space Communication Complex Facility Management	$200,000 (NASA contributes $22m)	• Portfolios that utilise the CDSCC include Astronomy and Australian Square Kilometre Array Pathfinder	Examples include Radio telescope operations, Radio science and engineering, Astronomy and astrophysics	• NASA • Provides access to the international radioastronomy community	• Critical support for spacecraft missions provided by receiving data and transmitting commands • Received first close up pictures of surface of Mars in 1965 • Support provided to human spaceflight programs	Options for continued world class astronomy research providing further understanding about the solar system and beyond Capability in the management of international scientific facilities Option to develop capability in high technology areas

Portfolio / Flagship / Facility / Collection / Platform	Goals	Themes	CSIRO expenditure* / yr	Supporting Divisions**	Capabilities used**	Clusters / examples of clients and/or partners	Selected outputs and outcomes / impacts	Options created
Manufacturing Materials and Minerals Group: contains the core of CSIRO's research focus in the materials, manufacturing, minerals, mining, chemicals, health and infrastructure sectors								
Materials Science and Engineering Portfolio	Transform existing Australian manufacturing industries to provide them with a sustainable, globally competitive future	Advanced fibrous materials Advanced engineered components Sustainable polymeric materials Industrial research services	$44.4m	• Land and Water • Process Science and Engineering • Materials Science and Engineering • ICT • Mathematics, Informatics and Statistics	Drawing on 17 capabilities, e.g. Metallic and ceramic materials, Super conductivity and magnetics, Polymers, Surface coatings, Fibre chemistry, Materials performance	• California Institute of Technology • Petronas Research • Commonwealth Department of Defence • Boeing Company • Advanced Manufacturing CRC Ltd • CRC for Advanced Automotive Technology Ltd • Huntsman Chemical Company Australia Ltd	• Knowledge for processing superfine Australian wool transferred to Chinese industry leading to reductions in processing costs and improved wool quality • Methods and apparatus for testing low flow showers developed	Option to make Australian manufacturing industries more sustainable and globally competitive
Molecular and Health Technologies Portfolio	Develop new technologies, with a focus on novel biological and chemical materials, to transform industries and improve health and wellbeing	National security technology partnership Australian biotech growth partnerships Biomedical materials	$38.7m	• Livestock Industries • Food and Nutritional Sciences • Marine and Atmospheric Research • Materials Science and Engineering • Molecular and Health Technologies • ICT	Drawing on 19 capabilities, e.g. Bioindustry product development, Molecular and cell biology, Protein expression and structure, Functional small molecules, Autonomous systems	• Australian Stem Cell Centre Ltd • Commonwealth Department of Prime Minister and Cabinet • Polymers CRC Ltd • Australian Research Council • DuPont • Vegenics Ltd	• Company established to commercialise polymer drug conjugate materials for ophthalmic and wound repair applications • Highly active compounds for HIV and Hepatitis C drug discovery delivered	Option to transform industries and improve health and wellbeing

Portfolio / Flagship / Facility / Collection / Platform	Goals	Themes	CSIRO expenditure* / yr	Supporting Divisions**	Capabilities used**	Clusters / examples of clients and/or partners	Selected outputs and outcomes / impacts	Options created
Future Manufacturing Flagship	Create new or significantly transform existing high value-adding, export-oriented sectors to improve the future competitiveness of Australian manufacturing. The objective is to have a $3 billion impact by 2020	Flexible electronics Nanosafety Biomedical manufacturing Clean Technology	$33.8m	• Process Science and Engineering • Materials Science and Engineering • Molecular and Health Technologies • Mathematics, Informatics and Statistics	Drawing on 18 capabilities, e.g. Wave physics, Integrated nanoscience, Surface coatings, Functional polymers, Supramolecular materials and interfaces	• Sensor Systems for Analysis of Aquatic Environments Cluster • Idemitsu Kosan Co Ltd • HySSIL Pty Ltd • University of Melbourne • Polymers CRC Ltd • Boeing Company • Australian Synchrotron Research Program Inc	• Geopolymers developed and potential applications as a building material being explored – HySSIL spin out – Work originated in the MSE portfolio • Device for diagnosing oesophageal disorders patented (clinical trial began in 2006) – Work originated in the MSE portfolio	Option to create new building materials and products Option to replace carbon intensive cement use in building construction with a technically and environmentally friendly substitute Option to reduce health care costs by quicker and more accurate diagnosis of digestive disorders
Light Metals Flagship	Lead a global revolution in light metals, doubling export income and generating significant new industries for Australia by the 2020s while reducing industries' environmental impact	Aluminium & magnesium manufacturing Alumina Aluminium Magnesium Titanium	$38.2m	• Land and Water • Marine and Atmospheric Research • Process Science and Engineering • Minerals Science and Engineering • ICT • Mathematics, Informatics and Statistics	Drawing on 18 capabilities, e.g. Alumina hydro-metallurgy, Process engineering, Metallic and ceramic materials, Surface coatings	• Australian Partnership in Light Metals Research Cluster • Breakthrough Technology for Primary Aluminium Cluster • General Electric Company • CAST CRC Ltd • Coogee Titanium Pty Ltd • Parker Centre Ltd • Commonwealth Department of Resources, Energy and Tourism	• High quality, defect free magnesium control arm parts developed • CASTvac technology adopted and expected to achieve savings of up to $500,000 per yr • Results from monitoring of global PFC emissions adopted by the IPCC	Option to develop new industries and improve environmental sustainability of existing industries

Portfolio / Flagship / Facility / Collection / Platform	Goals	Themes	CSIRO expenditure* / yr	Supporting Divisions**	Capabilities used**	Clusters / examples of clients and/or partners	Selected outputs and outcomes / impacts	Options created
Advanced Materials Transformational Capability Platform	Build programs that combine physics, engineering, chemistry and biology at an unprecedented scale to catalyse the development of materials of the future	NA	$5.06m	TCP's can fund their own projects drawing on staff from across CSIRO. They can also fund projects, in whole or part, in Divisional Capability Development Funds and Themes. Consequently the mix of Divisional staff contributing to a TCP changes regularly. Some examples might include: • Mathematics, Informatics & Statistics • Minerals Science and Engineering • Molecular and Health Technologies	Examples include Surface coatings, Fibre chemistry, Materials performance	• Main recipient of outputs is CSIRO, for example, Future Manufacturing • Beijing University of Chemical Technology • Curtin University of Technology • The University of Queensland • The University of Amsterdam • Monash University • Royal Melbourne Institute of Technology • Swinburne University	• Enhanced skills, expertise and know-how • Research infrastructure • Research relationships	Capability to accelerate ability to synthesise, characterise, and apply new advanced materials by fast-tracking the discovery process

Portfolio / Flagship / Facility / Collection / Platform	Goals	Themes	CSIRO expenditure* / yr	Supporting Divisions**	Capabilities used**	Clusters / examples of clients and/or partners	Selected outputs and outcomes / impacts	Options created
Minerals Down Under Flagship	Assist the Australian minerals industry to potentially exploit new resources with an in-situ value of $1 trillion by 2030, and more than double the size (to $10 billion per year) of the associated services and technology sector by 2015	Driving sustainability through systems innovation Discovering Australia's mineral resources Transforming the future mine Securing the future of Australia's carbon steel materials industry Creating wealth through advanced processing technologies Transforming productivity through on line analysis	$78.0m	• Land and Water • Sustainable Ecosystems • Earth Science and Resource Engineering • Process Science and Engineering • Materials Science and Engineering • Information and Communication Technology • Mathematics, Informatics and Statistics	Drawing on 33 capabilities, e.g. Environmental process engineering, Social and economic sciences, Regolith science, Computational geoscience, Mineral and environmental sensing, Mining automation, Precious and base metals hydrometallurgy	• Future Sustainability of Australia's Mineral Industry Cluster • Enhancing Heap Leaching of Nickel Laterite Cluster • AuScope Ltd • Centre of Excellence in 3D Mineral Mapping • Deep Exploration Technologies CRC • Parker CRC for Integrated Hydrometallurgy Solutions • AMIRA International • World Economic Forum study on the Global Future of Mining and Metals • Rio Tinto • BHP Billiton • Vale • BlueScope • OneSteel • Gold Fields Australia • Energy Resources of Australia (ERA) • Russell Mineral Equipment • Ground Probe • Transmin • Orica Mining Services • Boart Longyear	• CSIRO's HyLogger™ technology in widespread use at Geological Surveys and commercial labs across Australia • Potential large reductions in GHG emissions and water use identified from utilisation of bio-chars and dry slag granulation technology in steel plants • A Low Frequency Microwave (LFM) analyser to measure the moisture content of bulk ore streams carried on conveyors has been commercialised through the spin-off company Intalysis • Telerobotic control system developed for rockbreaker with some elements being commercialised • Swirl Flow mixing technology is in commercial use, resulting in reduced capital and operating costs of agitation systems in stirred tank reactors • Novel feedwell concept for use in gravity thickeners is in widespread use, resulting in improved efficiencies and reduced costs	Option to rapidly analyse exploration samples for key minerals of interest, enabling more targeted drilling Option to optimise operation of processing plants Option to obtain CO2 credits and reduce GHG emissions globally Option to convert waste material into useful products Option to control moisture content of bulk commodities, reducing dust emissions and transport charges Option to remove people from hazardous environments leading to improved health and safety performance Option to realise royalty / licensing revenue and achieve financial benefits across multiple metal / mineral commodities Option to achieve savings in water use and losses through more efficient recycling of plant water

* Planned total CSIRO expenditure from both appropriation funding and external sources for 2009-10 (CSIRO Operational Plan 2009-10), except for Transformational Capability Platforms, for which this figure represents the budget for 2008-09.

** From a source that has not yet been updated to account for deployment to the new themes in the Portfolios for Coal, Petroleum and Geothermal and MDU

C Capabilities used by Theme

The following table provides an indication of the range of capabilities used by each portfolio and theme across CSIRO. It was compiled as a tabulation of each theme against the team composition in 2009-10, based on 108 capabilities across CSIRO. It excludes additional capabilities sourced through external collaborative arrangements and it fails to count possibly key capabilities used in earlier years, thus feeding into 2009-10 work but not explicitly used in that year. These considerations suggest some, and in some cases significant, underestimation of the multidisciplinary diversity of the themes.

Portfolio	Theme No.	Theme Name	TOTAL FTE	Capabilities used
LMFS	1000	Aluminium & Magnesium Manufacturing	18.2	1
LMFS	1001	Alumina	37.5	10
LMFS	1002	Aluminium	24.4	12
LMFS	1003	Magnesium	5.1	3
LMFS	1004	Titanium	29.3	9
WfHC FS	1006	Urban Water	83.2	18
WfHC FS	1010	Integrated Water Information Systems	47.7	11
ET FS	1016	Energy Futures	14.5	7
ET FS	1017	Low Emissions Electricity	100.3	22
ET FS	1018	Low Emissions Transport	55.5	19
ET FS	1019	Low Emissions Distributed Energy	38.0	14
FF FS	1020	Future Grains, Grain-Based Food and Feed	70.7	13
FF FS	1021	Breed Engineering	46.6	14
FF FS	1022	Designed Food and Ingredients	43.6	13
FF FS	1023	Quality Biosensors	24.9	9
PH FS	1025	Colorectal Cancer and Gut Health	65.6	16
PH FS	1026	Neurodegenerative disease, mental disorder and brain health	51.2	14
FNS	1030	Transforming Food Manufacture	33.7	5
FNS	1032	Enhancing Food Benefit and Safety	40.6	6
CMSE	1036	Advanced Fibrous Materials	47.3	4
CPI	1038	New Horizons in Plant Science	51.4	6
CPI	1039	Delivering Quality Crops for Consumer Choice and Improved Industry Competitiveness	54.2	6
CPI	1040	Plant Fibre and Biofactories for New Agricultural & Industrial Products	100.8	9
CPI	1041	Designing Crops and Pastures for Australian Environmental Challenges	125.0	8

Portfolio	Theme No.	Theme Name	TOTAL FTE	Capabilities used
CORP	1043	IP Management (WLAN)	0.4	6
CLI	1044	Transforming Animal Biosecurity	71.7	4
CLI	1045	Transforming the Animal and its Products	60.8	6
FAC	1047	Diagnosis, Surveillance and Response	72.1	2
CMHT	1048	National Security Technology Partnership	25.3	8
CMIN	1053	Iron ore – Maximising Export Marketability	21.7	5
CMIN	1054	High-performance mineral processes for Australia	39.6	10
CMIN	1055	Instrument Systems for On-Line Analysis	26.0	1
DTS	1057	eHealth	18.0	2
DTS	1059	Broadband Wireless for Connecting Australia	24.3	2
WfO FS	1064	The Dynamic Ocean	52.2	7
WfO FS	1065	Ocean Based Industry Development & Growth – Blue GDP	85.2	25
FAC	1067	ATNF Operations	51.0	3
RA	1068	Technologies for Radio Astronomy	13.0	1
RA	1069	Astrophysics	22.0	1
ASKAP	1070	The Australian SKA Pathfinder	68.8	3
CENTO	1077	Invasive Species & Plant Biosecurity	71.4	13
CENTO	1080	Building Bioindustries with Synthetic Biology	44.7	8
CMHT	1088	Australian biotech growth partnerships	51.2	6
CMHT	1089	Biomedical Materials and Regenerative Medicine	79.7	12
FM FS	1090	Flexible Electronics	48.5	6
CPR	1092	Maximising Australia's Petroleum Self Sufficiency	60.0	5
FAC	1099	Marine National Facility	18.3	1
CMSE	1103	Advanced Engineered Components	53.9	15
CMSE	1104	Sustainable Polymeric Materials	34.6	5
CMSE	1106	Industrial Research Services	23.3	1
CEM	1115	Maximising the value of mining	50.9	6
CMAR	1132	Climate and Atmosphere	89.2	9
WfHC FS	1136	Healthy Water Ecosystems	86.4	18
WfHC FS	1137	Regional Water	101.6	18
ET	1140	Secure and Sustainable Energy Technologies	44.0	5
PH FS	1146	Obesity and Health	34.6	13
CA FS	1155	Pathways to adaption	41.2	11
CA FS	1156	Liveable Cities, Coasts and Regions	55.6	14
CA FS	1157	Managing Species and Ecosystems	25.0	8
CA FS	1158	Adaptive Enterprises, Industries and Communities	39.2	13

Portfolio	Theme No.	Theme Name	TOTAL FTE	Capabilities used
MDU FS	1160	Discovering Australia's Mineral Resources	77.0	10
MDU FS	1161	Transforming the Future Mine	47.9	10
MDU FS	1162	Securing Australia's Future Ore Reserves	36.6	11
MDU FS	1163	Driving Sustainable Processing through Systems Innovation	30.3	13
FM FS	1169	Nano safety	6.0	8
Biodiversity	1173	Building Resilient Australian Biodiversity Assets	126.3	10
FM FS	1175	Biomedical Manufacturing	28.4	10
FM FS	1176	CleanTech	23.1	11
WfO FS	1177	Our Resilient Coastal Australia	58.6	12
WfO FS	1178	Sustainable Ocean Resources	83.6	10
SA FS	1179	Greenhouse Gas adatement and carbon storage in land use systems	48.4	12
SA FS	1180	Advancing Agricultural Productivity and Environmental Health	115.5	15
SA FS	1181	Landscape Systems and Trends	60.8	19
SA FS	1182	Partnering for International Food and Fibre Security	16.8	7
DTS	1183	Service Oriented Systems	72.5	8

Data source: CSIRO

Note: The table has not been updated to account for the new themes in the portfolios for Coal, Petroleum and Geothermal and Mining Down Under

D Valuing carbon abatement

This attachment has been prepared to provide a logical basis for addressing the value and impact to be attached to CSIRO's work with the potential to support reduced GHG emissions. Given the current status of global and Australian policy settings in relation to carbon pricing and targets, this is a non-trivial issue which requires some care.

Australia is likely to receive little direct damage from its own carbon emissions, but shares strongly in a global interest in limiting atmospheric GHGs. Australia has assumed a strong policy position of international engagement in support of addressing global change. Australia has committed major resources to relevant R&D and there is recognition that Australia, with its very high carbon footprint, offers some scope for influence via international demonstration of an affordable mitigation strategy. This also means that threats of global damage from GHG emissions are a relevant consideration in assessing the value to Australia of innovation in less carbon intensive technologies that could be applicable internationally – and especially in a countries where coal-fired electricity generation is significant.

CSIRO's work on lower cost and/more broadly applicable strategies to limit carbon emissions without incurring unnecessary costs has the potential to contribute to these various dimensions of value. The challenge is to assess the value of such contributions in a way that does justice to the opportunities without overstating the value and impact.

D.1 Approach

In broad terms, we have favoured an approach that recognises:

- Direct value to Australia from innovation that may allow Australia to lower its costs of complying with emission targets, with this value being assessed as the resultant reduction in costs relative to the counterfactual.
  - We proceed on the assumption that a carbon market will emerge in Australia, and assume no direct reduction in Australian emissions, once the market is established.
    - … We do recognise potential for small short-term benefit as a result of emissions avoided, given that the ETS has been delayed.
    - … We also recognise that these technologies may permit Australia to adopt more stringent targets in the future, by lowering the cost of doing so – providing flexibility options to react to changing climate science or international commitment to climate mitigation.
- Some developments, such as very low emission coal-based electricity generation (via some form of carbon capture and storage), could offer

significant benefits to Australia via 'insurance' against dropping international demand for Australia's coal exports.

- The development of mitigation options with international application – as part of a suite of such developments from Australia and globally – may have a material impact on the timing and pattern of global commitment to mitigation.
  - As an indicator of the value of such innovations in contributing to global willingness to change, we propose the use of the social cost of carbon emissions that could be avoided through application of the technologies.
    - … We see this as highly relevant to CSIRO's function to support national objectives and Government processes.
    - … However, as indicators of global damage, these estimates are not seen as directly additive with the above values to Australia.

Our approach has been to focus on readily accessible, credible but conservative, indicators of value and impact capable of being applied across the range of work being assessed. We have not attempted sophisticated economic modelling to fine tune the estimates.

D.2 Abatement and the CSIRO portfolio

A common theme across many CSIRO research activities is the potential offered by an innovation to allow for reductions in emissions of greenhouse gases.

Even across the case studies undertaken in the present assessment, this potential appears in several places and is seen as a key reason for the research activity in a number of these. For example, it has emerged as:

- A central consideration in the work on cement substitutes, including geopolymers.
  - With successful delivery of a cost competitive alternative to concrete having the potential to lower Australian, and global emissions very significantly – and/or to lower the effective cost of any given level of abatement.
- A major driver of the work in relation to biochar – with application to both agriculture and steel production.
  - Again, success in developing a cost competitive product, and having it accepted for purposes of carbon accounting, could support very substantial reduction in net GHG emissions in Australia and internationally – and/or to lower the effective cost of any given level of abatement.
- A key driver of the work on the UltraBattery, with potential for reduced emissions in both road transport and stationary electricity generation.

- a driver of CSIRO's coordinated work across the entire climate strategy area, which includes strong elements of mitigation via reduced emissions or lower cost of abatement.
- a relatively new development with the Square Kilometre Array radio telescope project, which has been internationally agreed to have an integrated green energy solution, involving demonstration and implementation of a range of renewable and remote area power solutions.

More widely, CSIRO has for many years been a key player in the quest for low emission coal generation technologies and for a competitive carbon capture and storage technology based in geosequestration. This work is a key focus of the Energy Transformed Flagship, and CSIRO is engaged in a number of collaborative ventures addressing these issues. Other relevant of work include biofuels and other forms of biosequestration.

Collectively, this body of CSIRO activity is dealing with alternatives and smarter approaches to activities that account for well over half of Australian and global emissions of GHGs. Collectively the lines of attack show promise for creating options for quite dramatic reduction in the emissions intensity of a number of the activities – notably cement production, electricity generation, road transport and storage of carbon in soils.

Of course it would be optimistic to expect that CSIRO will roll out all the solutions to these challenges – and that solutions would not have been found without CSIRO. The realistic role of CSIRO is to:

- Contribute to bringing forward the likely time – the statistical distribution of the time – until substantial improvements are accessible.
  - It can do this even where the projects of CSIRO being first are small.
- Play a key role in ensuring that the form of the emerging technologies is suited to cost effective application in Australia.
- Help explore potential commercial opportunities for Australia that are associated with these technologies, this could include:
  - direct commercial opportunities to deliver the abatement services and technologies; or
  - opportunities for joint provision of desirable functionality in new products into markets;

    … while creating commercial and/or private incentives for reduced emissions;
- Play an active role in supporting appropriate rates of take-up of innovations in Australia; and
- Support Government processes both nationally and internationally.

All of these forms of engagement would appear clearly consistent with CSIRO's statutory functions, and aim to create clear impact.

D.3 Abatement options as core Government policy

The Australian Government has made a global attack on strategies for carbon capture and storage a key plank of its climate policy. In 2008, it announced the establishment of the Global CCS Institute, with foundation funding of $100m. The Institute became a legal entity in July 2009, with a large membership of governments, research organisations and companies around the world expanding both its financial base and its access to capability.

Substantial work is proceeding in Australia – driven significantly beyond the Federal Government engagement – by the Victorian Government in relation to Latrobe Valley emissions and economic prospects for alternative uses of brown coal, but with a wide range of other participants.

Australia is, of course, well placed to derive value from competitive carbon capture and storage technologies. They could have direct application in Australia, in securing the large investments that have been made in coal-fired electricity generation and the value of the coal sector – further supported by any effective role the technologies could play in supporting increased international demand for Australia's coal exports. They could also help to underwrite risks in making new investments in gas-fired generation – investments that are increasingly looking to the likelihood that eventual movement to carbon capture and storage may be needed to sustain competitiveness[4].

However, Australia also stands to gain from the potential these and other abatement technologies offer to support reduced global GHG emissions – especially in relation to economies such as China and India. A competitive retrofittable technology would have special attraction in this context, as well as for the Latrobe Valley

These views have contributed to the decision to make the Institute a global initiative. The Institute now has 226 members, including the following governments:

The Commonwealth of Australia
The Emirate of Abu Dhabi - MASDAR
The Government of Canada

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4 While substitution of gas for coal can substantially reduce emissions, the residual level of emissions from gas is likely eventually to become a constraint if aggressive abatement targets are implemented.

The Government of the Peoples Republic of China
The Republic of Bulgaria
European Commission
The Government of Egypt (Ministry of Petroleum)
The Government of the French Republic
The Federal Republic of Germany
The Government of India
The Government of Indonesia
The Government of Italy
The Government of Japan
The Government of the Republic of Korea
The Government of Malaysia
The Government of Mexico
The Government of Netherlands
The Government of New Zealand
The Government of Norway
The Government of Papua New Guinea
The Russian Federation
The Government of South Africa
The Government of Sweden
The Republic of Trinidad and Tobago
The Government of United Kingdom
The Government of the United States of America
The Government of Alberta
The State Government of New South Wales
The State Government of Queensland
The State Government of South Australia
The State Government of Victoria
The State Government of Western Australia

Australian and global negotiations on carbon policy settings recognise the importance of future technological change and innovation for limiting the damage from climate change at low economic cost. Massive innovation will be required over coming decades to constrain GHG emissions at an economic cost that is politically sustainable and broadly supports the economic aspirations of developed and developing countries.

Modelling of the proposed CPRS policy impacts in Australia assumed learning rates for key mitigation technologies that reflected historic ongoing incremental improvements in efficiency and cost. Naturally, this modelling takes an aggregated and long-term view of the rate of technological change that is largely independent of 'step change' improvements in individual technologies. Nevertheless, the cost of abatement modelled is predicated on such technological change occurring, the rate of which could be accelerated beyond that assumed through step-change innovations, or reduced through lower levels of private and public research and development spending or investment that is less effective than has been assumed.

It is also widely recognised that the affordability of carbon limitations in Australia is heavily linked to the level of restraint achieved internationally – and Australian Government policy has placed international influence alongside Australian mitigation and adaptation strategies – as one of the three central planks of climate policy.

Set in this context, if the emphasis were solely on the benefits to Australia from Australian implementation and export sales of technology, it would be possible to seriously under estimate the option and insurance value offered by CSIRO engagement with innovation in mitigation strategies. An approach is needed that can allow judgments to be made regarding value to national objectives and policy processes. This is not the same as saying that Australia is likely to have large international influence – but it does recognise several importunities that could merge and, alongside plausible developments elsewhere, deliver non-negligible influence over very large costs.

D.4 The social cost of carbon emissions

Translating CSIRO R&D prospects in this area into meaningful indicators of impact and value is far from straightforward. We have used an approach that at least allows some quantification of the scale of international promise offered by emerging CSIRO technologies where this may occur earlier or better than would otherwise be the case. This approach is based in the concept and estimates of the social cost of carbon (SCC).

The SCC is defined as the *damage associated with emitting one tonne of carbon*. It is defined at a point in time, relative to a one-off emission of carbon – or equivalently, as the damage avoided by preventing the emission of that tonne of carbon. The concept is generally defined in terms of overall global damage – though estimates are sometimes made of the implied damage to specific countries.

It is conventional to define the measure in $US terms. It can be expressed as damage per tonne of carbon, or per tonne of CO_2. Here we use the latter, allowing for easier comparison with the market price of emissions permit, that are commonly expressed on a per tonne of CO_2-e emissions. Care is needed in comparing studies – the Stern Report, for example, cited figures on a per tonne of carbon basis and these are necessarily much higher, by a factor of 3.67.

The SCC can be interpreted also as the marginal contribution made, by the last tonne of CO_2 emitted in a specific year, to the net present value of the forward stream of atmospheric GHG-related costs[5]. It may be well-defined but it is hard to measure with any precision. Apart from the limitations on current science, the actual value of damage will be a function of a complex array of future developments and current rates of time preference and attitudes to risk.

A modest discount rate, of around 3 per cent real, is typically applied. This is in line with WHO guidelines for assessing public health programs but does not align so well with conventional discount rates applied to investments. The fact that many of the damages would not be a financial kind may support a rate below the going cost of capital, as might concerns for intergenerational equity more generally. The social rate of time preference, not the social return on investment[6], would appear the more appropriate concept.

The SCC is not the same as the marginal cost of abatement (MCA). The SCC is concerned with the costs of failing to avoid a tonne of emissions, while the MAC is about the costs involved in avoiding that tonne of emissions. Standard economic principles suggest that you would seek to avoid emissions as long as the MCA is less than the SCC – and would support a 'perfect' carbon tax or market-determined permit cost under an ETS-style arrangement (which allowed for global trading) being at a price equal to the SCC.

Currently, there are no such arrangements in Australia, nor globally. The Australian Government had determined that an ETS, commencing in 2010, was appropriate policy. This arrangement has now been delayed, and timing and form is uncertain.

If such arrangements were in place and entailed a sustainable target level of long run abatement, then the SCC would be less significant. In this situation, given the target and using cost-effectiveness analysis, the costing would focus on the MCA and focus on least cost ways of meeting the targets (though knowledge of the SCC could pose a challenge for the agreed target given the MCAs). We note, that the UK, operating within a European ETS, has (since Stern) moved to this implicit assumption of a long term target and focused on the MCA.

Broadly speaking, Australian assessments have tended to move in the same direction. The 2008 Australian Government report, led by the Treasury and titled *Australia's Low Pollution Future* (ALPF), took this broad approach –

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5 In principle, this should also be net of forward benefits – including possible benefits to some crop production as flagged in Attachment E, and the subject of active CSIRO research.

6 The issues involved when assessing carbon mitigation benefits were addressed in Marco Boscolo, Jeffrey R. Vincent, and Theodore Panayotou (1998), *Discounting costs and benefits in carbon sequestration projects*. Harvard Institute for International Development Environment Discussion Paper No. 41. http://www.cid.harvard.edu/archive/esd/pdfs/iep/edp41.pdf

predicated at the time on expectations of an early move to a CPRS and expectations of a broader international movement in the same direction, with extensive trading.

Were emission trading schemes in place, expectations of a growing set of options, from R&D and from natural opportunities to replace 'lumpy' infrastructure etc, would tend to support an optimal level of abatement that rises over time towards 'sustainable' position. This reasoning underpins much of the modelling of GHG emissions control interventions, in Australia and overseas.

D.4.1 2010 SCC estimates by the US Dept of Energy

A number of estimates have been produced of the SCC. The US Department of Energy, as coordinating agency, has just released a report[7] prepared by a large multiagency group with advisers. The US report drew on a wide range of prior studies as well as its own commissioned modelling, and was finalised after seeking public comment. The estimates of SCC are viewed as being 'standard' inputs to the US required impact assessment processes used by agencies.

This 2010 US Department of Energy report suggested a 'central estimate', based on a 3% discount rate, of $US21 in 2010, rising to $US45 by 2050.

It should be noted that the report has been criticised on a range of grounds, most arguing that its figures *underestimate* the true SCC. A particular criticism is that it is biased downwards in the way it treats developing countries, in part by failing to recognise the heighted marginal value of a dollar of lost income in low income countries. The report recognises the issue and the plausibility of the argument – but chooses not to make the adjustment because of the complexities involved.

This *suggested source of downwards bias* is important in the current context, because of the strategic role seen for the SCC as an indicator of possible incentives for lower per capita income countries to adopt stronger mitigation measures. Essentially it suggests that these countries are likely to see the damage through a more intense lens than has been assumed.

[7] U.S. Department of Energy (2010), "Final Rule Technical Support Document (TSD): Energy Efficiency Program for Commercial and Industrial Equipment: Small Electric Motors," Appendix 15A (by the Interagency Working Group on Social Cost of Carbon): "Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866" Available online at http://www1.eere.energy.gov/buildings/appliance_standards/commercial/sem_finalrule_tsd.html

Further, it should also be recognised that the report relies on models, none of which accounts for the damage from ocean acidification nor the intangible costs of loss of species and ecosystems, both of which are potentially highly significant long term.

It is worth noting that the low discount rate of 3 per cent, as discussed earlier, is needed even to support these figures. Even a 5 per cent rate drops the $21 in 2010 to less than $5. On the other hand, use of a rate of 2.5% per cent raises the estimate to $US35.

The $US21 figure is accompanied by a 95-percentile estimate of $US64, rising to $US136 dollars by 2050, pointing to sensitivities to other assumptions made.

Assuming a medium-term AUD/$US exchange rate of 0.8, the 'central estimate' of $US21 in 2010 converts to about AUD27 – rising to about AUD $58 in 2050, after also factoring in adjustment from the 2007 dollars published. Many would argue that these figures are low and this seems plausible. Certainly the figures are low relative to the corresponding MCA expectations built into Treasury modelling of the ETS.

However, in the context of an attempt at providing credible indicators of value, with a preference for under- rather than overestimation, they may have a role – noting that these are estimates of the *global damage from marginal changes in emissions*.

Reflecting this, Table D1 summarises the key estimates produced by the US study.

Table D1 **Indicative estimates of global social cost of carbon (AUD/t CO_2)**

Discount rate	5%	3%	2.5%	3%
Year	Average	Average	Average	95th percentile
2010	6.1	27.8	45.6	84.4
2015	7.4	30.9	49.9	94.6
2020	8.8	34.2	54.2	104.9
2025	10.7	38.5	59.7	117.5
2030	12.6	42.6	65.0	130.0
2035	14.6	46.8	70.5	142.6
2040	16.5	51.0	75.9	155.1
2045	18.5	54.7	80.2	166.1
2050	20.4	58.4	84.5	177.1

Data source: US Energy Department (2010), adjusted to indicative AUD 2010 figures by ACIL Tasman

We stress that these are estimates of global damage from failure to mitigate at the margin. Even for the US, the direct country-level damage would be much smaller – the report suggests between 7 and 23 per cent of the global figure, while for Australia it would probably be an order of magnitude smaller again. Of course, global response cannot sensibly be based on each country counting all its costs on each initiative and only counting its share of the benefits – this approach would encourage severe underinvestment (and increase the risk of unmitigated major climate). The culture of science is particularly strong in its approach to 'give and take' across numerous blocks of work.

However, for many of the initiatives under consideration by CSIRO, the benefits to Australia would tend to come also from a non-zero chance of overseas adoption – and from the impact that the collective set of lower cost mitigation options has on willingness to reduce emissions internationally. In important respects, all the more so post Copenhagen, this could be viewed as the main game.

Against the above background, we would incline to the view that the average SCC figures are probably quite conservative, and that the 95-percentile figure could well seriously understate a 95-percentile that factors in all sources of damage.

The higher percentile figures are also important if it is recognised that the objective of climate policy is to mitigate the risks of damage associated with still quite uncertain forward climate scenarios. Optimal strategy is not about covering the average position – but about securing the flexibility to deal with plausible future threats affordably and cost effectively.

D.5 Earlier access to abatement options – ETS in place

In circumstances where a pure world-wide, market driven (with locked in emission targets) ETS-style mechanism had been established there is value in early access to lower cost abatement options. This value should essentially be the value of savings achievable by avoiding or deferring use of the highest cost abatement elements otherwise necessary to achieve abatement targets. Within such an arrangement, lower cost abatement options will alter the way in which the cap is met in a given year – but are unlikely to deliver any significant reduction in global emissions. The emissions will effectively be set by the cap.

This situation would favour an approach based around the marginal cost of abatement curve that applies in each year – with and without access to the new options. The difference between the curves – and in effect the area of the difference out to the cap that applies in that year – would indicate the savings enabled by the earlier access.

Of course, all the forward estimates of the price of carbon under an ETS will typically, as in the case of Treasury estimates for Australia, be based around an assumed rate of technological innovation. When considering the value of research undertaken by CSIRO to move the innovation possibilities towards achieving climate change mitigation, this consideration could create some circularity. Undoubtedly expectations of future technological progress include at least a component attributable to expectations of value delivered by CSIRO and researchers around the World.

Nonetheless, provided the counterfactual has been carefully considered, a 'with and without the CSIRO technology' assessment of cost differences should provide a useful indicator of value. For modest shifts in abatement, this is likely to be close to the modelled value of permits times the volume of abatement – less, of course, for larger impacts that would squeeze out lower cost options. The relevant marginal cost of abatement curve is not the modelled curve running into the future but the curve that applies in the year in which the extra abatement options are made available.

D.6 Earlier access to abatement options – no ETS in place

There are two distinct situations where the lack of a current ETS has relevance:

- A country like Australia, where there remain good prospects for some form of carbon pricing to emerge in the near term, inclusive of quantitative targets; and
- Other countries, notably China and India, where commitment to firm targets has yet to occur and may never occur.

In the former case, you might simply assume that the current permit price is zero, but will be rising from some date in the future, and the approach in Section D.5 is applicable. It would arguably be conservative for attaching zero value to any earlier abatement, before pricing comes in, when it is arguable that this abatement would still have an impact on medium term climate developments.

In the latter case, there are two relevant effects:

- If the new technologies make it attractive or acceptable for Australia or other countries to lower emissions, below the levels that would otherwise have applied, these could be valued at the SCC.
  - Noting that the SCC is a global cost, not an Australian cost, and therefore not additive to the abatement savings discussed above. This is a quantified indicator of impact on international influence, not a direct measure of benefit to Australia.
- The fact that abatement has been made more affordable, possibly while still consistent with a nation's development objectives, might result in a small

rise in the prospects for countries, particularly developing countries such as China and India, agreeing to a stronger commitment to climate change;

- Of course, it is likely that any impact due to CSIRO would need to interact with a large number of factors – including technological developments elsewhere, international negotiations and the concerns these countries have with the threat, to reach a 'tipping point'.

What is clear is that based on its size (population and GDP) Australia (and CSIRO) are playing a strong role in relation to a number of abatement technologies – CCS, concrete substitutes (including standards and testing), electric battery automotive technology and possible stationary energy storage etc – along with work on adjustment opens. Collectively, as was argued earlier, these could result in big changes in the cost of substantial abatement. In this context, the prospects for CSIRO's collective block of GHG mitigation work pushing these international positions to a tipping point would seem very *small but not negligible*.

The potential value for Australia in even a modest change in emissions by the larger developing countries as well as the emerging new developing giants suggests that a small probability times the resultant benefit could be reasonably large. Moreover, viewed as insurance that lowers the risks of catastrophic collapse in the development of an effective global mitigation strategy, some premium might even be justified.

Of course there is a need to be sober about the prospects, but we believe it is appropriate to recognise options of this type as potentially having significant value.

D.7 Summary

For Australia, the value of earlier access to abatement can be crudely estimated by comparing the time series of costs of meeting an assumed emissions cap, with and without the role played by CSIRO. This would typically involve the difference between the single year MCAs and the actual costs of abatement with the CSIRO technology.

E Climate Adaptation Flagship

E.1 Introduction

Over the last decade or so, Australia has been experiencing a range of manifestations of climate change (more heat waves, reduced rainfall, more severe droughts, more extreme weather events, more storm surges, etc.). There is a growing scientific and political consensus that climate change is linked to emissions of greenhouse gases. Furthermore, the science suggests that many of the impacts we are seeing are likely to continue to increase in severity for some time, irrespective of any steps that Australia (or the world) takes to try to mitigate greenhouse emissions.

Stern and Garnaut estimated the costs to the global economy of climate change in the coming decades to be of the order of 3-5 per cent of GDP a year. If we assume the impact on the Australian economy is at a similar scale and that the Australian economy is a trillion dollar one, then this suggests that the annual costs of climate change could be in the range of $30 to $50 billion a year. Clearly, the potential costs of climate change are substantial. This could be a relatively conservative estimate as many argue that Australia actually faces more risks from climate change than other parts of the world.

Consequently, measures that allow us to better manage these already "built in" climate change trends and hopefully reduce their adverse impacts will be increasingly important for the nation. Furthermore, given the limited progress made in international climate change negotiations to reduce global greenhouse gas emissions it seems increasingly clear that adaptation is the main option for dealing with climate change in the short to medium term. It could also provide added insurance against the risks of limited success in mitigation even in the longer term.

Adaptation actions aim to reduce the impacts, or the effective cost of the impacts, of climate stresses on human and natural systems.[8] As we discuss further below, there is a body of evidence that well designed adaptation measures can help reduce the cost of climate change. Adaptation measures can also be designed to harness any beneficial opportunities[9] that might arise.

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[8] The IPCC has defined adaptation as an adjustment in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts.

[9] While not wanting to suggest that current climate projections are good news, it could be very costly to ignore the fact that there will be some real upside opportunities that could be harnessed. For example, the evidence of rising atmospheric CO_2 concentrations is not seriously disputed, and has potential implications for crop productivity. Even those skeptical about climate implications should recognise an opportunity in the increased

However, ill informed, uncoordinated or poorly targeted adaptation measures could have severe economic costs due to inefficiencies, costs of missed opportunities and downside risks, particularly associated with prematurely locking in or out options to respond with greater flexibility to the actual course of events. These risks will tend to be greatest in relation to pre-emptive measures to create readiness for future conditions that remain uncertain as to timing and extent of impact.

One of the most important means of avoiding such costs for the economy will be to have better information upon which to base decisions. Consequently, deferring an irreversible commitment to incur an adaptation cost, pending more information being available upon which to base that decision can be a highly rational course of action.

The logical response is not, however, to avoid pre-emptive measures – it simply urges caution as to how this is done. People insure their houses, cars and selves as pre-emptive measures, given credible risks of serious damage and few would see this as irrational. It is crucial that the risks in delaying commitment be considered alongside the risks in committing. Furthermore, this 'trade-off' between competing risks can be relaxed considerably if it is possible to gain earlier access to better information about future developments and alternatives for adaptation. Better climate science, new technologies more suited to later retrofit and technologies that offer greater flexibility and robustness to deal with plausible alternative outcomes can all have a role to play in adding to the net value offered by adaptation – and in limiting the exposure to risks from adaptation investments that later prove 'regrettable'.

This point highlights the close inter-linkages that occur across the various elements of climate policy. Optimal adaptation strategy will be influenced by the quality of the climate science and the ability to forecast impacts over time and by the options available for mitigation. In turn, lower cost adaptation strategies could lower the optimal level of costs directed at mitigation as well as limiting the damage from failing to achieve optimal mitigation.

CSIRO is operating in all these spaces – and is increasingly focussing on careful coordination of the three areas. They should not be viewed as separate silos and CSIRO appears well placed to bring value to the coordination.

Below we examine some indicators of the plausible order of magnitude of a subset of the benefits that might reasonably flow from the options being developed through the work of the Climate Adaptation Flagship. These assessments take into account some views on risks and rate of roll-out of

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availability of a key input to crop production (namely CO_2), which could justify preemptive research to support its efficient utilisation.

potential benefits. While there is scope for disagreement on specific items, the narrow coverage of the benefits examined does lend some robustness to conclusions about cost justification.

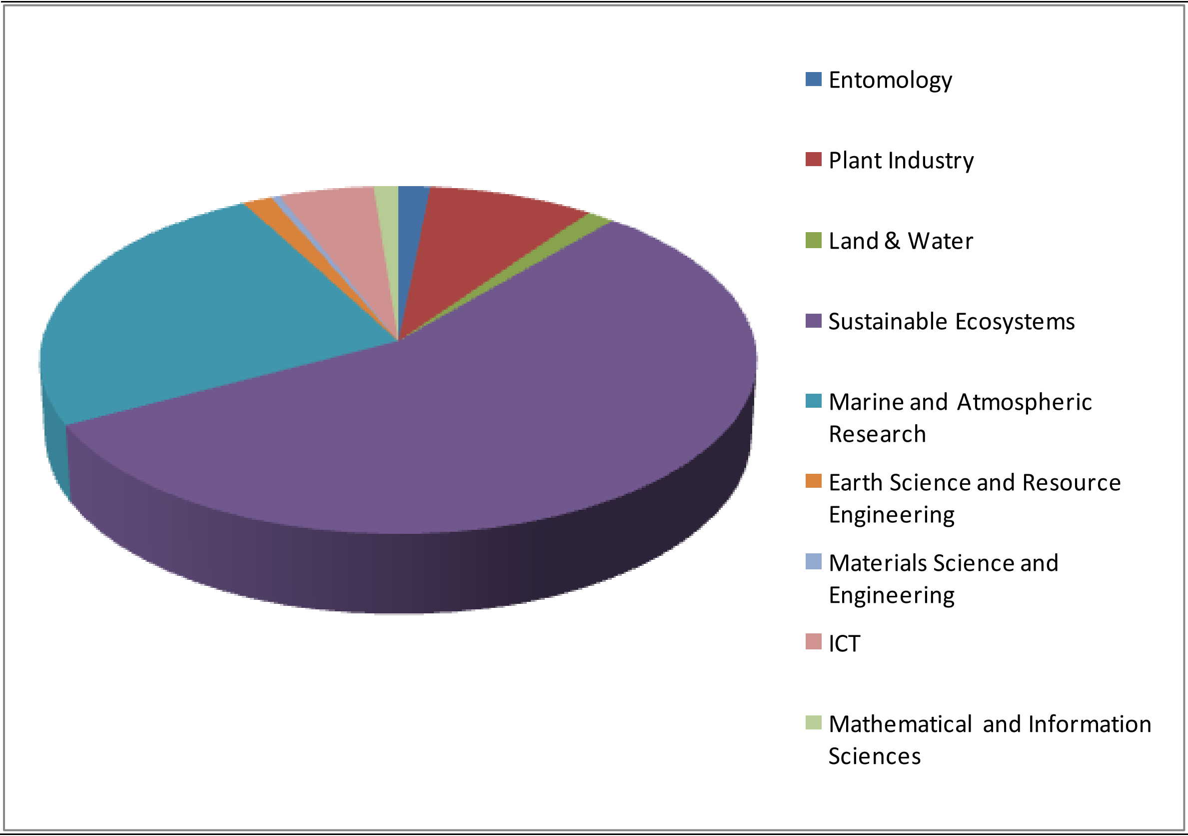
E.2 Flagship Origins

In April 2007, COAG endorsed a National Adaptation Framework as the basis for jurisdictional actions on adaptation over the next five to seven years, with possible actions to assist the most vulnerable sectors and regions to adapt to the impacts of climate change. In May 2007 the Commonwealth's budget allocations included a commitment of $26 million to establish and manage the Australian Centre for Climate Change Adaptation and $100 million in programme funding for the Centre over five years.[10] The Commonwealth also announced a new CSIRO Adaptation Flagship with funding of $44 million to provide more accurate information on localised climate changes. The Flagship was officially launched by Minister Carr in July 2008.

The Flagship brought together researchers from a wide range of CSIRO's scientific disciplines. The flagship has about 160 full time equivalent staff. Figure E1 shows the Divisions of CSIRO that these staff came from. Nine different CSIRO areas contributed to the establishment of the Flagship. Sustainable Ecosystems provided about half the flagship personnel, Marine and Atmospheric Research a further quarter and the remainder was split between seven other areas. In total, over 28 areas of expertise where drawn upon to form the Flagship.

[10] The National Climate Change Adaptation Research Facility (NCCARF) was launched in November 2007. NCCARF is working closely with the CSIRO Climate Adaptation Flagship, including being joint conveners of an international conference on Adaptation Futures to be held on the Gold Coast in mid 2010.

Figure E1 **Disciplines contributing to the work of the Flagship**



Source: CSIRO

E.3 Current status

The Climate Adaptation Flagship (CAF) aims to develop strategies to assist Australia not only to adapt to the impacts of climate change, but also to capitalise on any opportunities that may emerge. The Flagship has four main themes to its work:

- Pathways to adaptation – The Flagship will deliver detailed climate change information in user-friendly formats at local-scale, and identify potential responses and likely barriers to adaptation.
- Sustainable cities and coasts – under this theme Flagship researchers develop planning, design, infrastructure and management solutions to help Australia's cities and coasts adapt to a changing climate.
- Managing species and natural ecosystems – Flagship research is developing and delivering adaptation options to protect Australia's marine and terrestrial species, ecosystems and the services they provide from the impacts of climate change.
- Adaptive primary industries, enterprises and communities – the Flagship is developing adaptation options for Australia's primary industry and resource

sectors to reduce the vulnerabilities and enhance opportunities created by climate change and variability.

The Flagship's current strategic projects include:

- Better scenarios for Australia – this project seeks to provide more user friendly climate change projections and scenarios that can be used to consider local and regional (rather than national) impacts. This higher resolution information should greatly assist local planning efforts.
- Adaptive behaviours in Australian society – a project that will consider the behavioural, spatio-temporal, and economic factors that influence and motivate people when they make adaptive responses in highly uncertain and contested environments or situational contexts including climate variability and change
- Coastal vulnerability and planning – this is an important strategic research area that will produce reports like the recently published Sydney Coastal Councils report. It also has growing links to the Coastal Collaboration Cluster discussed below. This project is discussed in more detail in section E.4.3.
- Sustainable urban development – this strategic research area considers issues from the choice of building materials through to building, community and large scale urban design.
- Adaptive eco-engineering – a project that seeks to increase the sustainability of our ecology. It includes research into areas such as assisted migration of species and genetic traits that support adaptation. This project is discussed in more detail in Section E.4.3.
- Transforming rural regions – some climate change impacts will be of a scale that will force a complete change in the nature of agricultural activity in some regions. This project will seek to facilitate such shifts.
- Climate ready crops – a project that seeks to speed the development of new crops that are heat resistant, drought tolerant and adapted to higher CO_2 concentrations in the atmosphere. This project is discussed in more detail in section E.4.3.

Box E1 **Current and completed CAF projects**

The Flagship has a suite of current and completed key projects. For example:

- Drought Exceptional Circumstances report: www.daff.gov.au/agriculture-food/drought/national_review_of_drought_policy/climatic_assessment/drought-impact-report
- Extreme weather events: www.csiro.au/science/adapt-extreme-weather.html
- Climate change projections for Australia: www.climatechangeinaustralia.gov.au
- Indian Ocean Climate Change Initiative: www.ioci.org.au/
- The Pacific Climate Change Science Program: www.csiro.au/partnerships/Pacific-Climate-Change-Science-Program.html
- Resource efficiencies in Asia and the Pacific: www.csiro.au/science/Resource-Efficiency-Asia-Pacific.html
- Concrete durability: www.csiro.au/science/adapt-concrete-durability.html
- Eastlake – urban renewal project: www.csiro.au/resources/SCI-EastLake-FactSheet.html
- Your development website: http://yourdevelopment.org/
- South East Queensland Climate Adaptation Research Initiative: www.csiro.au/partnerships/seqcari.html
- Sleeper and alert weeds: www.csiro.au/resources/Sleeper-Alert-Weeds.html
- National Reserve System www.csiro.au/science/adapt-national-reserve-system.html
- Marine Report Card: www.oceanclimatechange.org.au/
- Mixed cropping and grazing: http://www.csiro.au/science/resilient-farmers.html
- Primary industries report: www.csiro.au/news/AdaptionForFarming.html
- Transforming primary industries: http://www.csiro.au/science/Industries-Transforming.html
- Climate ready crops. This project is discussed in more detail in section E.4.3.
- Managing extreme fire events (fire behaviour and building design). This project is discussed in more detail in section E.4.3.

Source: Personal communication with CSIRO, June 2010

E.3.1 Communication and collaboration

The Flagship has identified the adaptive behaviours in Australian society as an important issue. Improved communication between researchers and society is clearly an important mechanism for influencing those behaviours. Examples of communication products released by CAF include:

- a 6 page brochure on climate adaptation
- a 32 page adaptation booklet, due for release in June 2010
- *Adapting Australian Agriculture to Climate Change* book, released in March 2010 (now in second print run)
- CSIRO Climate Book, due for release in September 2010

Increased and improved communication about climate change impacts and adaptation also occurs indirectly. Many of the reports prepared by CSIRO have led to increased communication, particularly to convey the results of research to stakeholders. For example, the report for Western Port Greenhouse Alliance (WPGA) on the impacts of climate change on the communities in the region (to which the CSIRO was a major contributor) has led to a significant increase in dialogue about climate change impacts between councils and communities in the region.

Through its Flagship Collaboration Fund CAF is supporting a number of Clusters:

- Southeast Queensland Cluster was launched in 2009 and is a three year research program to develop practical and cost-effective adaptation strategies for the region. The Cluster looks specifically at human settlements, biodiversity and adaptive capacity. The cluster is led by Griffith University.[11] The Cluster is part of a larger program of work – The Southeast Queensland Climate Adaptation Research Initiative. The Initiative is funded by CSIRO, the Queensland Government's Smart State Innovation Fund and the Department of Climate Change and Energy Efficiency.
- The, soon to be launched, Urbanism, Climate Adaptation and Health Collaboration Cluster. The cluster's research program will focus on heat stress, food security and safety, air quality, and the changing risk posed by vector-borne diseases such as dengue fever due to climate change. The cluster will bring together scientists from a range of disciplines and organisations to develop adaptation strategies for safeguarding the health of our urban populations in the face of a variable and changing climate. The cluster will be led by the ANU.[12]

In addition, CAF is a partner in a third cluster established jointly with the Wealth from Oceans Flagship, namely a Coastal Collaboration Cluster. This cluster was launched in April 2010 and is led by Curtin University. The cluster

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11 http://www.griffith.edu.au/research/research-centres/griffith-climate-change-response-program/projects/south-east-queensland-climate-adaptation-research-initiative

12 http://www.csiro.au/partnerships/ClimateHealthCluster.html

will integrate diverse social sciences to make scientific, community, indigenous and managerial knowledge available to coastal policy-makers and planners and investigate how to help coastal communities maintain economic and social values while using ecosystems more sustainably.[13]

The Flagship also participates in a joint Stakeholder Advisory Group with the Commonwealth Department of Climate Change and Energy Efficiency. This group meets twice a year. The Flagship and the National Climate Change Adaptation Research Facility are joint conveners of an international conference on Adaptation Futures to be held on the Gold Coast during 29 June to 1 July 2010.

E.4 Structure of Benefits of the Research

In the following subsections, we work through several of the areas where the work of the Climate Adaptation Flagship may generate value. We draw on some of the available literature and discuss possible scenarios, likelihoods and values.

The discussion that follows is intended to reflect broad classes of possibilities rather than scripted certainties. Notwithstanding the completion of some initial studies, the reality is that much of the research now being undertaken is at a stage where it is just not possible to predict with great precision what the eventual outcomes might be. Reflecting the options perspective, the research is exploring selected areas and, in doing so, attempting to expand the amount of available information and the associated options. That is not to say that the objectives of the research are unclear, but rather that the nature or extent of the outcomes are in some cases substantially unknowable.

E.4.1 Comments on timing of costs and benefits

A challenge with any pre-emptive investment in adaptation capability, especially in relation to long-lived assets, can be the long lags between incurring costs – for example the costs of limiting development, imposing building requirements designed for a possible future – and the actual occurrence of the climate change effects that were used to justify the investment. In circumstances like these, conventional discounting will lead to quite harsh cost benefit assessments, by virtue of the fact that future benefits will be more heavily discounted than the present costs. These risks are further exacerbated by uncertainty about the extent to which the change in climate and in extreme weather events will occur and the time periods involved.

13 http://www.csiro.au/partnerships/Coastal-Cluster.html

Reflecting the above discussion, this points to the high value in earlier access to better local information on which to base such decisions. It may also mean that pre-emptive investment is not justified – or that there could be large gains in determining if there could be a 'retrofittable' response allowing flexibility to delay costs until they are needed. The potential value of early research that improves information of this type can be very large – in avoiding unnecessary costs.[14]

However, pre-emptive strategies implemented early can look a lot more attractive if there is pre-existing reason to make the investment, even if it is not quite strong enough, on its own, to justify the investment. In these cases, the net cost of the pre-emptive strategy – net of the early benefits even without large climate change impacts – could then be low enough to justify action.

The CAF is exploring strategies with characteristics of this type. For example, below we consider investments in increased safety in bushfires against the backdrop of recent experiences of death, injury and loss of property. Innovations that address the immediate threat, while offering insurance against some of the potentially growing threat, could then be highly cost effective. Heat stress of crops is a current risk – robust farm strategies that limit the risk have immediate value and likely growing value. Furthermore, work done in this direction in the short term could provide a high value platform for ramping up these strategies as climate outcomes become clearer.

Against this background, care is needed in approaching the benefits of programs for climate adaptation. Analogous issues arise in a number of areas where CSIRO is operating – including river and groundwater management under the Water for a Healthy Country Flagship. Better water resource management is a pressing and immediate need, with the potential to lessen the damage from projected changes to the climate.

As a general comment, we feel that, given the scale of plausible threats, and the likely potential of adaptation to lessen damage, it would be a mistake to underestimate the *value of insurance against particularly damaging outcomes*[15] that could be achieved through attacking the information constraints early. These constraints include the availability and quality of local climate projections and

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14 Stephane Hallegatte *Strategies to adapt to an uncertain climate change*, Global Environmental Change 19 (2009) 240–247,

15 The community has shown a clear, and well-founded, willingness to pay insurance premiums in excess of actuarially determined average claims precisely for the immediate value of improved risk management. Judging the value of insurance investments solely in terms of outlays against expected claims could lead to serious underinvestment in insurance. We believe the CAF, and wider CSIRO engagement with climate-related issues, does include major elements of insurance value.

risk scenarios, the scope for developing more robust adaptation strategies given the remaining uncertainties and, included in this last group, the scope for developing strategies for retrofitting that limit the trade-off between certain short-term cost and plausible long-term benefit.

E.4.2 General benefits of adaptation

Stern and Garnaut estimated that the cost to the global economy from the impacts of climate change could be some 3-5% of GDP a year.[16] Assuming an Australian economy of about $1trillion suggests that, in Australia's case, this would suggest that costs of climate change could be of the order of $30 - $50 billion a year.

Some relatively modest assumptions regarding the contribution that the Climate Adaptation Flagship (CAF) might make towards reducing the economic costs of climate change would support the Flagship's stated Goal, namely to:

> Equip Australia with practical and effective adaptation options to climate change and variability and in doing so create $3 billion per annum in net benefits by 2030.

The Garnaut report discussed the expected economic costs of unmitigated climate change for the Australian economy.[17] Figure E2 shows the estimated percentage reduction in GNP as a result of climate change relative to a reference case.

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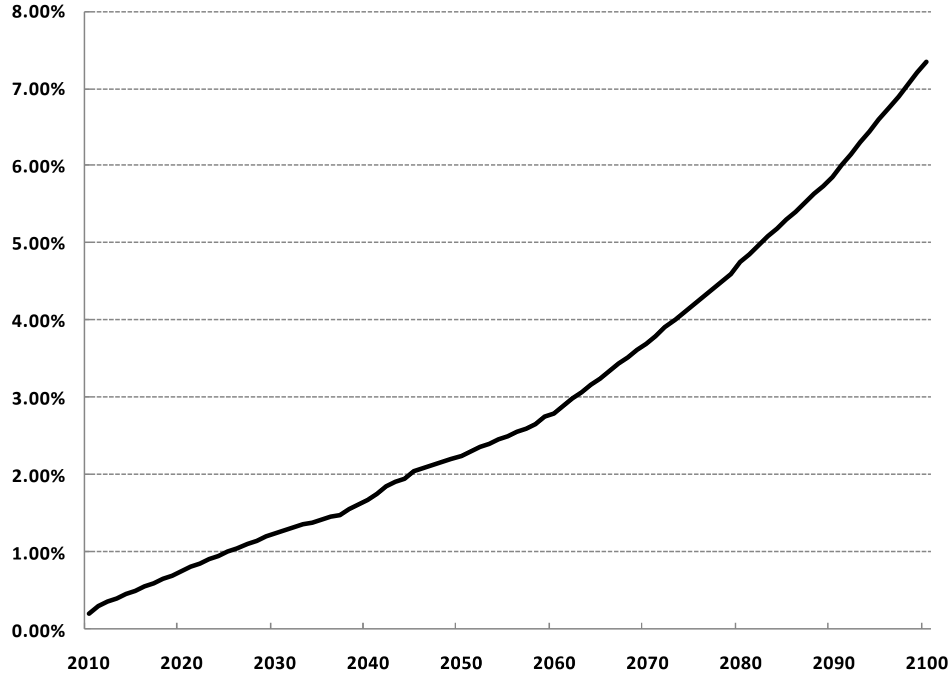
[16] See for example Figure 11.6 on page 267of *The Garnaut Climate Change Review: Final Report,* Commonwealth of Australia 2008

[17] *The Garnaut Climate Change Review: Final Report,* Commonwealth of Australia 2008

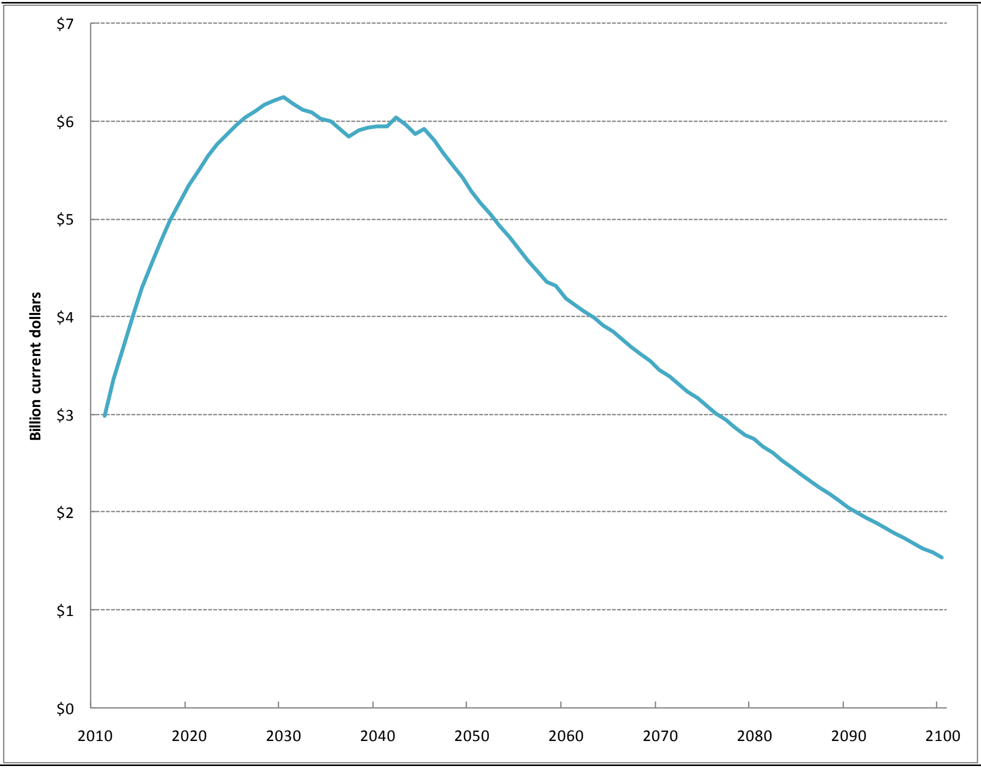
Figure E2 **Per cent of GNP lost due to the impact of climate change**



Data source: Reproduced from Figure 11.6 (page 267) in *The Garnaut Climate Change Review: Final Report*

The same report provided average annual growth rates by decade for GDP between 2000 and 2100. Based on this data, the data shown in Figure E2 and the actual GDP figure for 2009 we have calculated the NPV (at a 7% discount rate) of annual lost GDP between 2010 and 2100. The results are shown in Figure E3.

Figure E3 **NPV of annual GDP foregone ($million)**



Data source: ACIL Tasman calculations based on data in *The Garnaut Climate Change Review: Final Report*

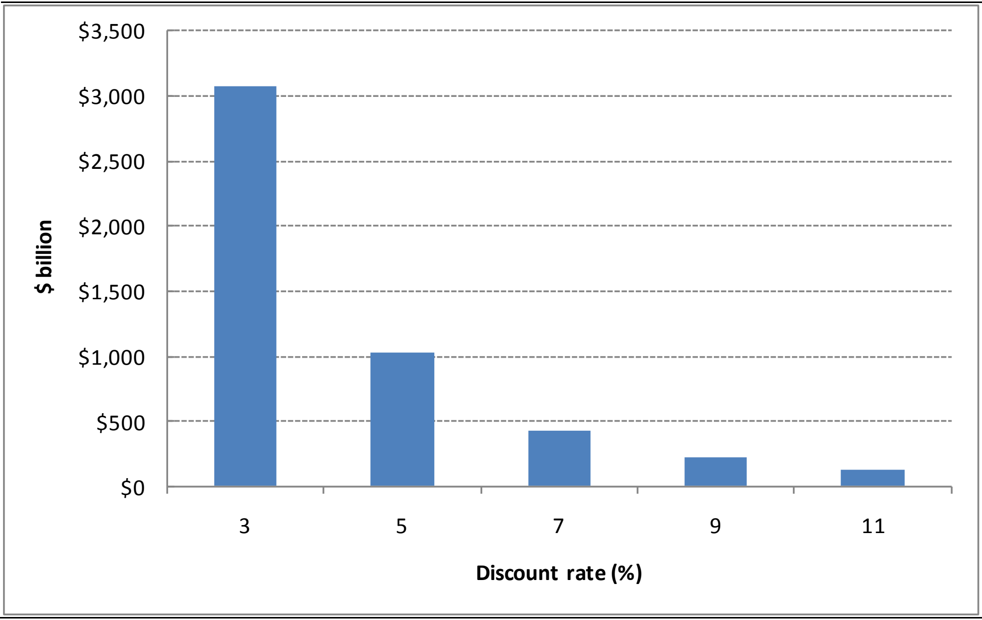
We see from Figure E3 that the NPV of the annual economic cost of climate change is estimated to increase from around $3 billion in 2010 to around $6 billion a year by 2025, stay roughly at that level until around 2045 before slowly declining to around $1.5 billion by 2100.

There has been considerable debate about the appropriate discount rate to apply to the costs of climate change. A figure around the long term bond rate is traditionally used by governments, whereas businesses tend to use figures above 10%. Others have argued that in the case of intergenerational issues such as climate change much lower discount rates should be used. Figure E4 illustrates how the NPV of total annual foregone GDP over the period 2010 to 2100 varies with changes in the discount rate.

ACIL Tasman has selected a discount rate of 7% for use in our analysis. While we believe that this is a relatively conservative assumption, even higher discount rates still result in large NPV numbers for foregone GDP.

Unless otherwise specified, the discussion that follows refers to calculations that use a discount factor of 7%.

Figure E4 **NPV of total GDP foregone from 2010 to 2100 ($billion)**



Data source: ACIL Tasman calculations based on data in *The Garnaut Climate Change Review: Final Report*

There is an expectation (see the discussion in Box E2) that adaptation might reduce those costs by about half. Many climate adaptation possibilities are strongly regionally dependent, with limited scope for simply 'importing' solutions.

More broadly, systematic consideration of potentially cost effective adaptation options can be viewed as sound *insurance against the risks of locking into unnecessarily high costs* flowing from climate change risks, and may support cost effective deferral of some high cost mitigation measures that might later prove to have been unnecessary or excessively costly. This favours an approach that looks closely at how the Climate Adaptation Flagship could create value in a range of ways – from low regrets adjustments to behaviour through to insurance against substantial failure in international mitigation efforts.

Box E2 outlines some of the analysis that lends support to the view that adaptation can help to reduce the costs of climate change impacts.

The NPV of the foregone GDP over the period between 2010 and 2100 is a very significant amount (around $400 billion using a discount rate of 7%). Clearly, the extent to which Australia was able to reduce the loss of GDP by even a relatively modest proportion through risk based adaptation measures that took into account the projected impacts of climate change could generate significant benefits.

Box E2 **Value of adaptation in reducing costs of climate change**

CSIRO provided some analysis and numbers that lend support to the supposition regarding the reduction in costs associated with the impacts of climate change as a result of CAF's work. The key findings from each of these reports are summarised below:

- A CAF publication, *Australian agriculture adapting to climate change: balancing incremental innovation and transformational change* reported on a study by Howden and Crimp in 2005 that found that some simple agronomic adaptation options for the Australian wheat industry might increase farm-gate income by an average of between $150 million and $500 million a year by 2070.
- A report based on a study by a partnership of the Global Environment Facility, McKinsey & Co, Swiss Re, the Rockerfeller Foundation, ClimateWorks Foundation, the European Commission and Standard Chartered Bank, entitled *Shaping Climate-Resilient Development – a framework for decision-making* developed a cost benefit framework and applied it to examine the impact of adaptation measures in eight case studies around the world. The report found that between 40 and 68 percent of the economic loss expected over the period to 2030 could be averted through adaptation measures.
- Analysis by ABARE on the effect of the adaptation measures in two agricultural regions in Australia was reported in the 2007 March quarter edition of *Australian Commodities*. ABARE found that adaptation measures could reduce the severity of the impact of climate change on total factor productivity by close 50 per cent (for wheat, beef, sheep meat and wool production).

Sources: As described in text above

It is reasonable to assume that Australia is already beginning to adopt measures aimed at helping us adapt to the impacts of climate change. However, it is open to argument whether adaptation measures being adopted now will reduce the projected GDP losses by as much as the 50% discussed above. ACIL Tasman has assumed that the total benefit from adaptation measures will not exceed 10% in 2010 but that it will slowly increase to 50% by around 2050 and remain constant at that level out to 2100.

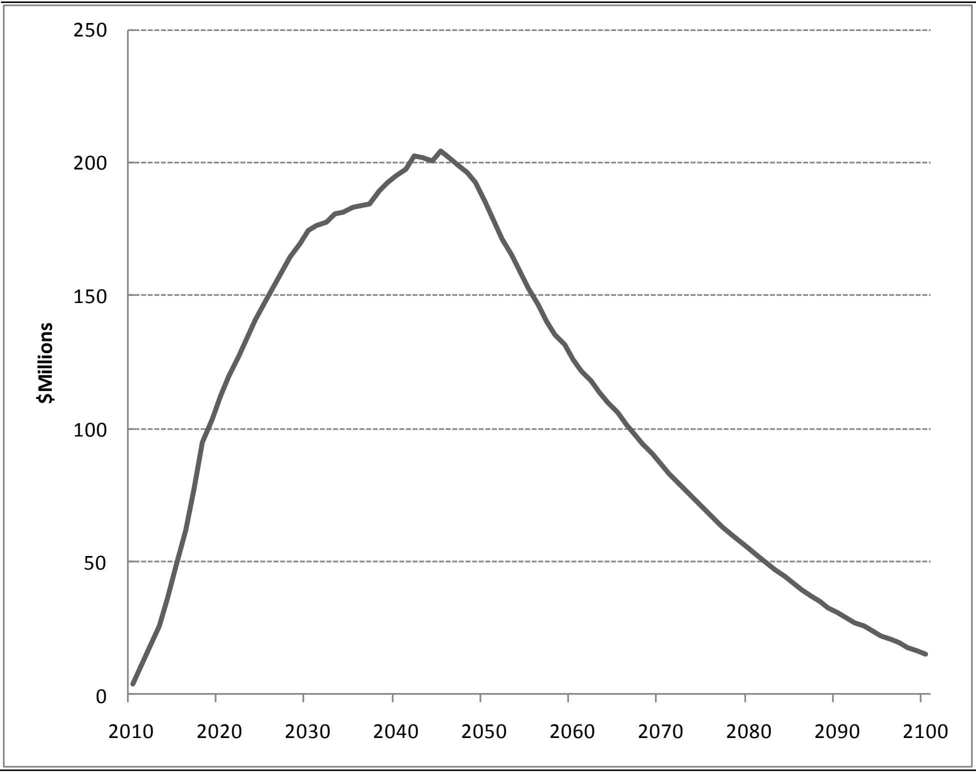
Similarly, ACIL Tasman believes it is reasonable to assume that some component of any reduction in the loss of GDP that occurs as a result of adaptation would be due to the research done by the Climate Adaptation Flagship. For the purposes of our calculations we have assumed that the share of any reduction in to the loss of GDP that can be assigned to the Flagship will be relatively small to begin with (2% in 2010), but that that share will increase relatively rapidly (by 1% a year), to a maximum of 10% in 2018 after which it will remain constant until 2020 before declining slowly over the period to 2100.

This takes into account the fact that the Flagship has only been operating a short time. Notwithstanding that the research done by the Flagship is already clearly having an impact on decisions, it will take some time for the research effort to be disseminated throughout the government and community into policy and action and to fully bear fruit. Since the Flagship currently has a finite life we have also assumed its share of the reduction in GDP loss declines over time.

However the rate of decline in the Flagship's share is much slower (we have assumed by 0.1% a year) since much of the benefit from adaptation will be delivered over a long period of time as many of the adaptation decisions will continue to deliver benefits over the life of the infrastructure or the management of natural resource systems in question. For example, coastal infrastructure built to take account of the projected increase in sea levels could easily have a life of 40-50 years.

Figure E5 shows the results of ACIL Tasman calculations of the annual NPV amount by which GDP losses are reduced due to adaptation measures that are linked to the outcomes of Flagship research over the period 2010 to 2100. The data shown in Figure E5 suggest that the NPV of the cumulative benefits of the Flagship's research will exceed the $44 million in funding provided for the Flagship by 2013.[18]

Figure E5 **Annual (NPV) amount by which GDP losses are reduced due to adaptation linked to Flagship research**



Data source: ACIL Tasman calculations based on data in *The Garnaut Climate Change Review: Final Report*

[18] Note that CAF also receives funding from the Government through the CSIRO internal budget. Total funding from this source was some $1 million between 2007/08 and 2010/11.

The NPV of the benefits of the Flagship's research between 2010 and 2030 are over $2 billion, a return of over forty-five to one on the government's investment in the Flagship.

Again, we would note that the assumptions we have made to arrive at this result are, we believe, very conservative.

It is also notable that a range of adaptation measures that might sensibly be considered from an Australian perspective could have application to other countries facing threats of serious damage from climate change.

E.4.3 Some specific examples

The Flagship is undertaking research across a wide range of subject matters and there is no scope to examine the impact of each of these pieces of work. Rather, we have selected four projects undertaken by the CAF with the aim of examining these in greater detail to illustrate the value of the research done by the Climate Adaptation Flagship. In selecting projects we endeavoured to select projects that were representative of the broad direction of the research being undertaken by the Flagship. They vary in size and cost and are a mixture of completed work and work that is still underway. The three projects relate to:

- Bushfires
- Coastal communities
- Climate ready crops

The following three sections discuss each of these projects in turn. We also present the results of our analysis of the value delivered by these research projects done by CSIRO.

E.5 Bushfire research

E.5.1 Background

Bushfires are common in Australia and are an unavoidable part of nature's regenerative process in Australia. The southeast of Australia, where the majority of the population lives, is susceptible to severe bushfires that threaten both life and property. The risk of bushfires is exacerbated by the droughts that occur as a part of the natural variability of our climate, while severity and damage can be heavily related to temperatures and wind conditions.

While bushfires pose a risk to life and property, most Australians genuinely love the bush and living in communities surrounded by bushland is considered as a desirable life style option by many Australians. The increase in people making a "tree change" move is testimony to this love of the Australian bush.

Australia's most recent major fire disaster occurred in Victoria in 2009. The Black Saturday bushfires resulted in a substantial loss of life and injury. Of the 173 people who died as a result of the fires, 164 died in the fire, of these 113 died inside houses, while 11 people died in vehicles, another five died near vehicles. Only one fire fighter died fighting the fire when a burnt tree collapsed onto his tanker during the mop-up phase. In addition to the people living with burns and other injuries, the fire also resulted in a mass loss of public and private infrastructure.

The actual cost of the Victorian bushfire in terms of lost property is still being determined. However, Emergency Management Australia has reported that the Insurance Council of Australia had received more than 8,000 claims with an estimated insurable cost of $1.02 billion by 4 March 2009.[19]

While Australia experiences bushfires most summers, major losses of life and infrastructure are less common. GeoScience Australia[20] reports that the other major bushfire events which have made critical threats to life and property have occurred in:

- 2006 in South Australia on the Eyre Peninsula where nine people died as a result of the fires and another 110 were injured. The fire burnt out more than 145,000 hectares of land including 48 thousand hectares around the townships of Wangary, Wanilla, North Shield, Pooinindie, Louth Bay, Greenpatch and Yallunda Flat near Port Lincoln
- 2003 in Canberra where four people died, more than 100 were injured and 500 homes were lost
- 2001-02 in New South Wales and the ACT where widespread severe bushfires burnt through the Christmas period, burning many hectares of land, but with no loss of life or major property losses
- 1983 in Victoria and South Australia, where as a result of the Ash Wednesday fires 28 people died in South Australia and 47 died in Victoria, including 13 Country Fire Authority employees and two other fire fighters. More than 2,670 were injured in these fires. Property losses where high and included 2,019 houses and more than 1,250 farms damaged.
- 1967 in Tasmania around Hobart, where as a result of the fires 62 people died and another 900 were injured. More than 3,000 buildings were destroyed, including 1,293 homes. Around 265,000 hectares was burnt out destroying public infrastructure including bridges and power poles and the

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19 Australian Government, Attorney Generals Department, Emergency Management Australia, EMA Disasters Database, http://www.ema.gov.au/ema/emadisasters.nsf/c85916e930b93d50ca256d050020cb1f/99b5a9963369d3e0ca25755b001d41f1?OpenDocument.

20 Geoscience Australia, Major Historic Bushfires, http://www.ga.gov.au/hazards/bushfire/historic.jsp

like. The farming community was also badly hit by the fires with considerable property damage and loss of crops, forests and animals. GeoScience Australia reports "The original estimated cost of the fire in 1967 values was A$45 million with insurance losses of A$14 million".

- 1939 in Victoria, where the Black Friday fires destroyed 1,300 building including 700 homes and 69 sawmills.
- 1926 in Gippsland Victoria, where as a result of the fires 60 people died and with widespread damage to, or destruction of farms, homes, sawmills and 400,000 hectares of forests.

Clearly with the major losses to life and property arising from these, what might be considered infrequent but devastating events there are grounds to consider investing in insurance to minimise the damage that is done. CSIRO's bushfire research can be considered as one example of the insurance that Australian Governments have taken out to help Australians understand bushfires and take action to minimise the damage arising from bushfire.

E.5.2 CSIRO research

CSIRO has been involved in bushfire related research for over forty years. One notable outcome of this research was the development of the Forest Fire Danger Index, in 1967. This index has since played an important part in Australia's bushfire warning system.

Over that time CSIRO has built and retained considerable expertise and capabilities across areas such as:

- understanding and predicting bushfire behaviour
- the impact of bushfires on materials and infrastructure
- ecological responses to fire
- the impact of climate change on bushfire risk.

Research results have been used to respond to bushfire threat through weather warnings, fire location information, fire-fighter training, predicting fire behaviour and informing fire safety policy. Obviously, much of CSIRO's work on bushfires predates the formation of the Climate Adaptation Flagship. However, the CSIRO's experience and capabilities in bushfire research has been brought inside the Flagship envelope to allow it to better integrate complementary research in areas such as climate change modelling, urban design, materials science and so on.

Some specific examples of how CSIRO bushfire research may deliver value are discussed below.

Climate change and bushfire weather risk

CSIRO research has highlighted that the risk of Australia experiencing more major bushfire events is increasing. CSIRO's climate change projections indicate that the southeast region of Australia is likely to become hotter and drier in future. In 2007, the Climate Institute of Australia and the Bushfire CRC funded CSIRO and Bureau of Meteorology scientists to examine the historical record of the Forest Fire Danger Index (FFDI) at 26 selected Bureau of Meteorology observing stations. The likely impacts of future climate change were calculated for each of those stations.

The CSIRO modelled low and high global warming scenarios. By 2020, the increase in the cumulative FFDI was generally between 0-4% for the low warming scenario and 0-10% in the high scenario. By 2050, the increase was generally 0-8% (low) and 10-30% (high).[21]

The changes in annual cumulative FFDI values mask much larger changes in the number of days with significant fire risk. The daily fire danger rating is classed as 'very high' for FFDI greater than 25 and 'extreme' when FFDI exceeds 50.

The 2007 report broke new ground by defining two new ratings 'very extreme' when FFDI exceeds 75 and 'catastrophic' when FFDI exceeds 100.[22] The frequency of more severe fire danger days is projected to increase over time with the highest increases seen for the high global warming scenario. For example, the number of 'very high' fire danger days increases by 2-13% by 2020 for the low scenarios and 10-30% for the high scenarios. By 2050, the range is much broader, generally 5-23% for the low scenarios and 20-100% for the high scenarios. Similarly the number of 'extreme' fire danger days increases by 5-25% by 2020 for the low scenarios and 15-65% for the high scenarios. By 2050, the increases are generally 10-50% for the low scenarios and 100-300% for the high scenarios.

In short, the CSIRO's modelling suggests that fire seasons will start earlier and end slightly later. Also the seasons will generally be more intense throughout their length and the frequency of days with extreme or catastrophic ratings are projected to rise dramatically over the next few decades.

Reflecting the increased severity of fires Australia's states and territories in 2010 introduced a new national Fire Danger Ratings (FDR) framework, which

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[21] ACIL Tasman notes that climate observations are currently largely in line with or above the high scenarios modeled by the IPCC.

[22] Bushfire Weather in Southeast Australia: Recent Trends and Projected Climate Change Impacts, C. Lucas, K. Hennessy*, G. Mills and J. Bathols, Report prepared for The Climate Institute of Australia, September 2007

includes Severe, Extreme and Catastrophic (or Code Red, where the Fire Danger Index exceeds 100).

Understanding bushfires

To assist in the understanding of bushfires and how flame fronts interact with machinery and infrastructure CSIRO scientists developed a large scale Bushfire simulator at the Eurobodalla Rural Fire Service Training Facility which is located near Mogo, NSW.

The simulation facility at Mogo was initially set up by CSIRO to undertake research to improve the safety of fire trucks (discussed below). However, the facility has been used to improve knowledge on the safety of motor vehicles in a fire front and is currently being used to undertake research into how materials and structures respond to fires. This later work has been an important input to the development of an Urban Design Bushfire Vulnerability Assessment Tool.

Fire truck safety

On Wednesday 2 December 1998 a bushfire near the Victorian town of Linton caused the death of 5 fire fighters when their fire truck was subjected to a burn-over event following a wind change. This tragedy was instrumental in the Country Fire Authority (CFA) seeking assistance from the CSIRO to conduct research on how to improve the safety of occupants of fire trucks in such situations.[23]

CSIRO's Mogo bushfire simulator was used by scientists in the Forestry and Forest Products Division and the Manufacturing Infrastructure Technology Division to help design and test a range of bushfire protection systems for fire trucks. Those systems include drop down curtains to shield the occupants from radiant heat, fire blankets, heat shielding on critical truck components and a water spray system to protect the truck. These safety measures began to be incorporated in the CFA fire trucks in 2005/06, with about 40 new trucks a year being built to replace older trucks.

The value of the new protective measures were demonstrated in the February 2009 Victorian bushfires. Twelve fire trucks were subject to a burn-over event during that fire, however there was no loss of life as a result.

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[23] While the deaths of the fire fighters in the Linton fire was the driver for the start of CSIRO's bush fire research it was not the first time there had been such deaths. For example, twelve fire fighters died in fire trucks in the Ash Wednesday fires in February 1983.

While the CFA is not able set a number on the number of lives saved, they are firmly of the view that there would have been lives lost in the absence of the new safety measures. It is difficult to establish exactly how many lives were saved as a result of the CSIRO research, the fact that each fire truck carries a crew of five tells us that the upper bound on the potential deaths from the twelve burn-over events could have been as high as 60. The fact that one fire truck was completely destroyed by a burn-over event suggests that a conservative lower bound on lives saved might be five people.

It is also difficult and potentially controversial to put a value on human lives saved. However, one approach, which has been used in the past and that is recommend by the Office of Best Practice Regulation (OBPR) for use in cost benefit analysis of new regulation that is aimed at reducing the risk of physical harm, is the value of statistical life.[24] The OBPR recommends that departments and agencies use the estimate of $3.5 million (2007 dollars) for the value of statistical life.[25] Assuming CSIRO research resulted in five fire fighters lives being saved in the twelve burn-overs, this equates to $17.5 million (2007 dollars) of benefits.

ACIL Tasman understands that the CFA are now seeking to speed up the introduction of the fire truck safety systems across their entire 2000 truck fleet by proposing a program to retrofit their existing trucks. CFA and CSIRO have been working together to validate the performance of the next generation of fire tankers, the Mogo bushfire burnover facility was used again in March 2009. WA and SA are also moving to apply the lessons learnt from the CSIRO research. However, resource constraints have restricted the ability of NSW to apply the results of the research to its fleet.

Passenger car safety

The test facility at Mogo has also been used to test domestic passenger car behaviour in a burn-over event and approaches for improving the survivability of the occupants in such an event.

The research indicated that the alignment of the car to the fire front and the behaviour of the occupants could improve survivability by between 30 and 50 per cent. The findings were put into practice, forming the basis of a number

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24 Office of Best Practice Regulation, *Best Practice Regulation Guidance Note, Value of Statistical Life*, http://www.finance.gov.au/obpr/docs/ValuingStatisticalLife.pdf

25 This value represent an average is based on a healthy person living for another 40 years. Note the OBPR recommends that this 2007 dollar estimate should be indexed by the CPI.

of revisions of the AFAC[26] policy for surviving passenger vehicle burnovers. This policy is in turn used by fire agencies in their education programs.

As noted above, in the most recent Victorian bushfires 11 people died in vehicles and another five died near vehicles. It is not possible to say if the loss of life would have been different if the knowledge gained from CSIRO's research had not been put into practice.

However, community education based on CSIRO's findings could potentially have saved lives and continue to do so in the future. That said, education on the newly introduced Fire Danger Ratings framework, and the better understanding of when to stay and defend and when to leave is likely to be of much higher value in terms of lives saved. This value is realised through individuals' improved understanding of risks associated with a bush fire. Thus, allowing them to make an early decision to retreat when a forecast fire weather event may exceed the capacity of their home to survive.

Building standards

The Victorian Bushfire Royal Commission second Interim report, released in November 2009, contained a number of recommendations in regards to the need for a national standard for bushfire bunkers and urgent changes to building standards for buildings in bushfire prone areas.[27] In March 2010, the Victorian Government announced it was bringing forward the introduction of new Australian design standards for buildings in bushfire prone areas. Under the new standard new homes in high risk areas must be made of non-combustible materials.

The Mogo facility has also been used to test the behaviour of different materials and structures during a bushfire. For example, CSIRO in partnership with the National Association of Steel-Framed Housing and the Bushfire CRC have recently used the Mogo facility to flame test steel-framed houses under a range of bushfire conditions. The results of this research are still being analysed. However, it is reasonable to expect that research of this kind will inform the development of building codes in bushfire prone areas around Australia and broaden the range of functional and cost effective design solutions available to the public.

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26 Australasian Fire and Emergencies Services Authorities Council

27 2009 Victorian Bushfires Royal Commission, Interim Report 2 – Priorities for Building in Bushfire Prone Areas, http://www.royalcommission.vic.gov.au/Interim-Reports.

Recent research reveals that the majority of house losses have occurred on days when the FFDI exceeds 100.[28] The same paper notes that for a FFDI above 50 (for a standard fuel, 12 t/ha), direct suppression of a fire front in a forest is no longer safe or effective, highlighting the fact that urban design, the rural/urban interface, brigade intervention and community preparedness are the only remaining effective defence mechanisms. The fact that the frequency of days with FFDI's greater than 50 is projected to increase highlights the value of improved understanding of fire danger and building standards.

Urban Design Bushfire Vulnerability Assessment Tool

Whilst new building standards are a means of minimising bushfire risks for new buildings, risks remain high for existing houses and other buildings in fire prone areas around Australia.

The information gained through the CSIRO's research has been coupled with fire behaviour modelling software to create an Urban Design Bushfire Vulnerability Assessment Tool. The tool enables users to download topological information from Google Earth, position existing buildings or structures at specified locations on the resultant map, select the materials they are constructed from and then introduce a fire front that interacts with the environment created.

The Assessment Tool can be used to determine where the greatest risk of fire damage will come from and help to determine what retrofitting can be done to improve safety.

The Tool is currently being trialled with various fire agencies and is reportedly likely to lead to a step change in thinking about how to design for improved survivability of buildings under the projected higher fire risks in future.

The Urban Design Bushfire Vulnerability Assessment Tool could lead to a significant shift in how new buildings are designed and old buildings are retrofitted to deal with the projected increased risks from bushfires. If the Tool is successfully introduced for use by all Australian home owners living in bushfire prone areas, its advice, if implemented, could potentially save many properties and lives in future major bushfire events.

As noted previously, bushfire events are expected to become more frequent and more extreme than in the past. Given that the property costs alone of the 2009 Victorian bushfires resulted in more than 8,000 insurance claims with a

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[28] *Meteorological conditions and wildfire-related house loss in Australia* Raphaele Blanchi, Chris Lucas, Justin Leonard and Klara Finkele, paper accepted into the International Journal of Wildland Fire

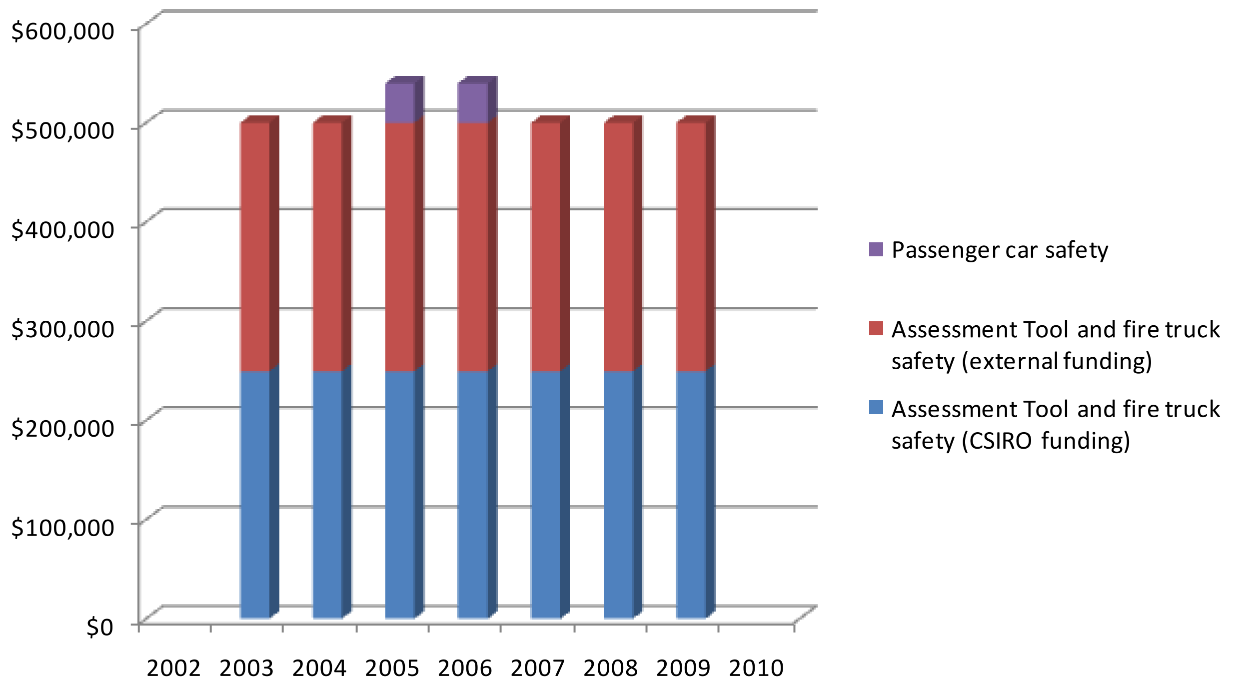
value of $1.02 billion, a reduction in future claims from extreme bushfire events of only 10 per cent, could lead to average savings in terms of lost or damaged property in the order of $120 million (2009 dollars) for a single major event.

Of course the value of life saved by sheltering safer buildings could be expected to exceed this indicative property saving by many millions. As discussed above, 113 of the victims of the 2009 Victorian fires died in a house and the value of statistical life, associated with just one life saved is $3.5 million (2007 dollars).

E.5.3 Cost of the research

The cost of developing the Urban Design Bushfire Vulnerability Assessment Tool and improving fire truck safety was some $500,000 a year between 2003 and 2009. Funding was split evenly between CSIRO and external funders (see Figure E6). The safety research on passenger cars was a one off project costing some $80,000 over two years. The total nominal cost of this investment in bushfire research was $3.5 million, of which $1.75 million was directly provided by CSIRO. In real 2010 dollars the cost equates to just over $5 million of which around $2.5 million was directly provided by CSIRO.

Figure E6 **Cost of research on fire truck safety and car safety in bushfires**



Note: The above data only reflects the funding for the components of the overall bushfire work mentioned in the figure title.

Source: CSIRO personal communication May 2010

E.5.4 The counterfactual

The Mogo facility was the first of its kind and reportedly remains the only facility of this kind in the world. The test facility, coupled with the fire behaviour modelling skills available within CSIRO, was instrumental in delivering the research outcomes described above.

Stakeholders expressed the view that the combination of available skills and experience within CSIRO was critical to the delivery of the research outcomes. ACIL Tasman estimates that it would take some ten years to develop those skills and experience in the absence of CSIRO having taken on this task.[29]

E.6 Coastal communities

E.6.1 Background

A number of different estimates of sea level rise have arrived at similar figures for annual average global increases in sea levels of around 1.5 mm a year for the period 1961–2003. [30] More recent observations suggest that the rate of sea level rise increased to 3.1 mm a year in the period 1993 to 2003.

The observed rise in sea level is currently tracking at or near the upper limit of the IPCC's projections. Figure E7 shows the IPCC's projections for sea level rise to 2050. The upper limit of those projections suggests that sea levels might rise by between 15 and 20 cm by 2030. Note that local sea level rises might vary, sometimes substantially, from each other for reasons such as vertical movement in the continental plates.

As sea levels rise over the next few decades the risk of coastal inundation is expected to increase. The risk of inundation is likely to be exacerbated if the projected increases in storm intensity occur over the same time frame. Similarly, any growth in coastal populations would increase the number of people, houses and other infrastructure that are at risk of an inundation event.

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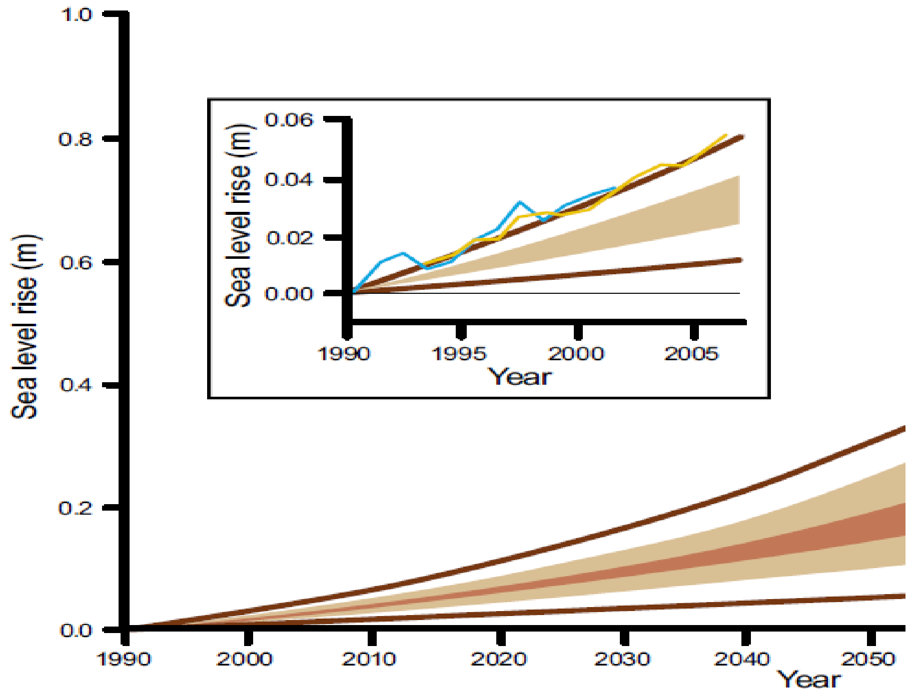
[29] This is based on the years of experience in the field that the lead researcher had prior to the bushfire research project commencing.

[30] *Climate change 2009 - Faster change and more serious risks*, Will Steffen, Department of Climate Change, 2009 and *Improved estimates of upper-ocean warming and multi-decadal sea -level rise,* Domingues, C.M., Church, J.A., White, N.J., Gleckler, P.J., Wijffels, S.E., Barker, P.M. and Dunn, J.R. (2008) Nature 453: 1090–1093,

Figure E7 **Projections of sea-level rise to 2050 from the IPCC Third Assessment Report**



Note: The Third Assessment Report projections are indicated by the shaded regions and the curved lines are the upper and lower limits. The inset shows sea level observed with satellite altimeters from 1993 to 2006 (yellow) and observed with coastal sea-level measurements from 1990 to 2001 (blue).

Source: Reproduced from *Climate change 2009 - Faster change and more serious risks,* Will Steffen, Department of Climate Change, 2009,

In recent years there have been a number of decisions which have shown that there is an increased willingness of Australian courts and tribunals to bring climate change considerations into the planning process. For example:

- In 2007, the Queensland Court of Appeal upheld a condition that made the Applicant move a house site to avoid excessive fill which would be required due to the flood risks associated with climate change. (Charles & Howard v Redland Shire Council [2007] QCA 200)
- In 2008, the Supreme Court of South Australia upheld the Council's decision to refuse a development by Northcape Properties on the basis that the predicted sea level rise over the next 100 years due to climate change provided an unacceptable risk to the subdivision. (Northcape Properties Pty Ltd v District Council of Yorke Peninsula [2008] SASC 57)
- In 2008, the Victorian Civil and Administrative Tribunal refused consent for a housing development in South Gippsland because of climate change considerations, including the threat of increasing storm severity and rising sea levels. In this case the proposed sea wall was not considered sufficient to protect land from future potential sea level rises and storm events. (Gippsland Coastal Board v South Gippsland SC & Ors (No 2) [2008] VCAT 1545).

Even though the extent to which the impacts of climate change are taken into account in the planning and decision-making process is still evolving, court decisions such as those above suggest that developers' proposals will increasingly need to consider the impacts associated with climate change to ensure that their development is allowed to proceed. Indeed, the City of Casey in Victoria now requires developers of any land that are deemed to be at risk of inundation to conduct a Coastal Hazards Vulnerability Assessment as part of the development approvals process. This decision was based on the results of the study of the impacts of climate change on the Westernport region carried out by CSIRO and others.[31]

A key difficulty for developers and infrastructure builders is that they will increasingly need to factor in the potential risk of sea level rise in their proposals while at the same time there remains a lack of scientific certainty regarding the magnitude of sea level rise.

E.6.2 CSIRO research

CSIRO has been carrying out research to support the adaptive capacity of councils in a number of regions, including in South East Queensland, Westernport in Victoria and with the Sydney Coastal Councils Group. The goal of these projects has been to explore the issues of climate change vulnerability, risk management and adaptation, with a focus on the adaptive capacity of local councils to address issues of regional significance. For example, the report 'Mapping Climate Change Vulnerability in the Sydney Coastal Councils Region' was initiated to address an identified lack of regionally-specific information that could assist councils to plan for the effects of climate change.

E.6.3 Cost of the research

The work on coastal community projects has been supported by the Australian Government Department of Climate Change and Energy Efficiency (DCCEE) under the National Climate Change Adaptation Program (NCCAP).

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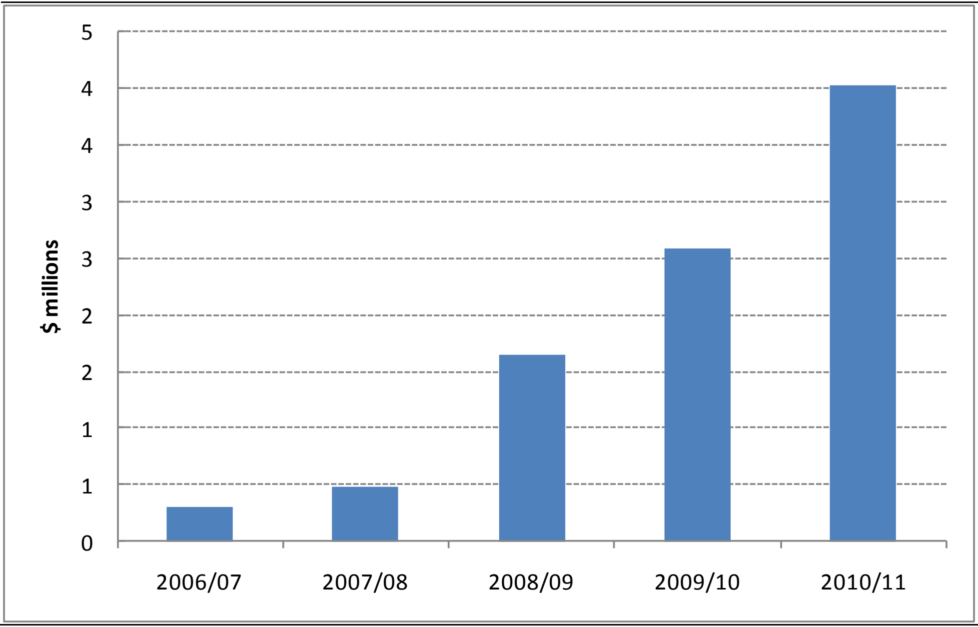
31 *Impacts of Climate Change on Settlements in the Western Port Region - People, Property and Places*, CSIRO and Marsden Jacob Associates, June 2008

Figure E8 **Cost of Flagship research on coastal communities**



Source: CSIRO personal communication June 2010

The cost to government of supporting the research on coastal communities was just over $9 million. The work has also been supported via third party funding. For example, the vulnerability work for the Sydney Coastal Councils is supported by in-kind assistance from the Councils of $443,000.

E.6.4 Benefits of the research

There are a number of overseas studies that flag both the potential costs of sea level rise and the potential value in better management of the risks.

- Mimura and Harasawa estimated the cost of maintaining the functions of Japanese infrastructure with a 1 metre rise in sea levels at 11.5-20 trillion Yen. This was equivalent to $149.5 billion –$260 billion.[32]
- Yohe and Schlesinger conducted a cost benefit analysis in 1998 on adaptation decisions in a sample of the developed coastline of the United States. [33]
  - estimates in their study revealed a cost of protecting or abandoning developed coastal property in response to a 1 metre rise in sea level with and without foresight of US$4b and US$5b respectively.
  - these estimates were at the national level, and used a 3% discount rate.

[32] Mimura, N. and H. Harasawa, Data Book of Sea-Level Rise 2000. Centre for Global Environmental Research, National Institute for Environmental Studies, Environmental Agency of Japan, Ibaraki, Japan, 2000, 280 pp.

[33] Yohe, G . W. and M.E. Schlesinger (1998), *Sea level change: the expected economic cost of protection or abandonment in the United States*.

The above results were based on a substantial rise that is likely to be a long time coming. However, more recent results from CSIRO suggest that the risk of significant costs could arise even at lower levels of sea rise. The research done by CSIRO may be able to reduce some of these costs if it reduces uncertainty and better informs policy. Notably, the second of the above studies suggests that the scope for realising benefits (in the form of reduced costs) through adaptation is significant.

The work of CSIRO is intended to provide coastal communities with the information they need to better plan for the impact of climate change and through adaptive measures reduce the potential costs of climate change on their communities. It is certainly plausible that better information could contribute through reducing costs either by avoiding unnecessary responses and or delivering cost effective pre-emptive adaptation.

There is a range of potential adaptation responses to the projected higher risk of inundation. These include reactive responses, such abandoning damaged or destroyed properties after a flood has occurred. Alternatively, pro-active measures such as constructing flood barriers could be taken to reduce the impact of an inundation event.

For example, possible measures could include:

- Develop maintenance programs for individual properties and public infrastructure such as roads, drains, and bridges to defend against minor inundation.
- Put in place barrages on the main access waterways into near-sea-level inland estates.
- Improve engineering structures on frontal dunes to protect against erosion for beach front properties.
- Upgrade design standards for new houses (and public infrastructure) within existing at-risk areas, to increase resistance to inundation events.
- Promote or permit house insurance premiums that are scaled relative to whether houses are best-practice flood resistant in flood prone areas.
- Develop effective early warning systems and evacuation pathways for extreme events.
- Prevent or restrict new development in coastal areas judged to be most at risk.

CSIRO has prepared a preliminary assessment of the costs of inundation and the benefits of proactive, planned adaptation in South East Queensland (SEQ).[34] They did so by estimating the population and economic effects of an

[34] Personal communication based on yet to be published CSIRO analysis, June 2010.

historical 1-in-100-year inundation event and then exploring how those effects may change under different adaptation scenarios out to 2030 and 2070.

In SEQ the upper range of sea level rise, under a mid level emission scenario is projected to be some 20 cm by 2030 and 50 cm by 2070.[35] Storm surges due to extreme weather events will be more intense and frequent, with the current 1-in-100-year event occurring as often as every 61 years by 2030. Thus, taking into account, the mean sea level rise, the upper range of a current 1-in-100-year peak storm surge (which is currently 2.5m) may reach 2.7m by 2030 and 3.0m by 2070, while a current 1-in-500-year surge event may reach 3.4 m in 2030 and 3.7m in 2070.

CSIRO believes that these estimates may be conservative as they do not account for all factors which contribute to sea level rise such as accelerated melting of Greenland ice sheets.

CSIRO considered a number of possible scenarios to assess the benefits of alternative adaptation options. They included:

1. A business as usual scenario where unrestricted development is allowed to continue with unchanged building regulations. Population and number of homes continue to expand at currently forecast rates in areas at risk.
2. Planning regulations are tightened to prevent further development in areas at risk, but no actions are taken to protect existing stock.

The potential cost in terms of damage to housing stock and evacuation costs was assessed for each of these scenarios and compared to the cost of a 2.5m storm event today (this is a one in a hundred years event). Note that the impact of a 2.5m storm surge event in 2030 will be augmented by the projected 20cm sea level rise (to 2.7m) by 2030. Similarly, a 2.5m storm surge in 2070 would lead to a 3m deep inundation.

Table E1 **Estimated impact of a 1:100 event in SEQ under scenario 1**

	Today	2030	2070
Area affected	$42km^2$	$48\ km^2$	$57km^2$
Water depth	2.5m	2.7m	3.0m
Population exposed	226,500	399,400	772,300
Houses exposed	35,200	61,550	121,400
Cost of impact	$1.1b	$2.0b	$3.9b

Note: Cost of impact does not include costs of impacts on commercial buildings, roads or railways
Data source: Unpublished CSIRO analysis

35 ACIL Tasman notes that observed changes in the climate are currently tracking at or above the projections for high level emission scenarios.

Table E2 **Estimated impact of a 1:100 event in SEQ under scenario 2**

	Today	2030	2070
Area affected	42km^2	48 km^2	57km^2
Water depth	2.5m	2.7m	3.0m
Population exposed	226,500	245,100	273,000
Houses exposed	35,200	40,280	47,000
Cost of impact	$1.1b	$1. 3b	$1.5b

Note: Cost of impact does not include costs of impacts on commercial buildings, roads or railways,
Data source: Unpublished CSIRO analysis

Table E1 and Table E2 show the impact of a 2.5m storm surge in 2030 and 2070 on population and homes at risk under each of the above scenarios.

These tables suggest that introducing measures to restrict further development in areas judged to be at risk due to sea level rise could reduce the potential cost of a 2.5m storm surge event in SEQ in 2030 by some $700 million. The similar potential reduction in costs of a 2.5m storm surge event in 2070 is closer to $2.4billion. This is significantly in excess of the reported cost of about $9 million for the coastal communities program since 2006/07.

The above estimates suggest that one could estimate the average cost of a 1:100 year inundation in 2030 as being about $7 million and that this increases to $24 million by 2070.

These cost estimates are probably conservative for a number of reasons, including because they:

- do not take into account the projected increase in the severity over time
- only consider the impact of a one in a hundred year inundation, whereas in realistic there are a wide range of inundation risks associated with both smaller (and more frequent) and larger (and less frequent)storm surges.

For example, data on the cost of coastal floods in SEQ between 1974 and 2008 tells us that the average annual cost of inundations in that region over that time period was close to $130m. This average cost hides significant annual variability, with the cost of individual inundation events varying from $4 million to almost $2.1billion. (All amounts referred to above are in 2009 present value dollars).[36]

These figures of course make clear the potential, in line with the discussion in Section E.4.1 above, that there is scope for early investment to limit future costs associated with climate change, thus delivering significant early benefits with some certainty, alongside insurance against future risks. These early

[36] Unpublished CSIRO paper that reproduced Insurance Council of Australia data.

benefits are likely to be of considerable importance in weighing whether early action is cost effective.

In 2006 the Insurance Council of Australia made a submission to the Council of Australian Governments (COAG) on Natural Disasters in Australia. That submission estimated that there were some 711,000 buildings at risk of coastal inundation in Australia.[37] This suggests that a possible upper bound on the potential cost of an inundation in Australia could be of the order of $20 billion.

Tightening planning regulations is an option with relatively low direct costs. However, the accumulation of benefits could be relatively slow, although a 1:100 event could in theory occur at any time (as could a 1:500 year event), and, as noted above, the Average Recurrence Interval (ARI) of an inundation that is today classed as a 1:100 year event will drop over time as sea levels rise and storm intensities increase.

There are also opportunity costs associated with restricting coastal development since it prevents the development of flood prone coastal areas that may be regarded as having high real estate/amenity values in the short term. For example, in Queenscliff, Victoria, some 20% of the Council's income from rate-payers is judged to be at risk of inundation. The Council initially sought to restrict further development in the area. However, the community opposition to this move was so great that they are now considering what appropriate design criteria should be applied to any new development. However, the option of progressively encouraging residents to move out of the area at risk is still seen as a longer term option.

E.6.5 Conclusions

The CSIRO work will help coastal councils to take better decisions on what measures (such as more restrictive planning regulations) to put in place, when to put them in place and in what areas they should apply.

Intuitively, gains in this area seem plausibly large. To the extent that good time series data will prove a prerequisite to delivering these capabilities, the case for keeping open the options afforded by this class of research would seem substantial.

Even if we took the average annual cost of past inundations in SEQ, ie $130m, as the possible future cost and assumed that the same ratio of savings as suggested in the US study on the value of foresight then the saving due

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37 This Insurance Council of Australia commissioned work assumed that buildings less than 3km from the coast and less than 6m above sea level were at risk of coastal inundation. Most of these were buildings on the eastern seaboard.

CSIRO's research in one year would be $26m – with a conservative present value, if sustained, of the order of $200m (though the counterfactual is important here). This potential saving from this single stream of research compares favourably with the total government funding of $9 million for the coastal communities program.

E.6.6 The counterfactual

It is unlikely that any other single organisation would have had the combination of climate change modelling, engineering and materials science, geospatial and social science skills required to undertake the analysis done by CSIRO, at the time it was done. We would expect that the demand would have encouraged the emergence of an analogous capability in time – but by then a lot of major decisions might already have been locked in.

It is possible that the same research could have been done piece by piece by different organisations, but it would probably have taken longer and cost more as all the various skilled people would need to be identified and brought together to carry out a collaborative program of research similar to that done by the CSIRO.

Importantly, the costs of getting this work done seem almost unavoidable. The risks have been recognised and the demand has emerged from councils, planners etc. The central question is the extent to which CSIRO was able to do the work earlier, more effectively and with greater influence. We incline strongly to the view that this is the case.

E.7 Climate ready crops

E.7.1 Background

Australian agriculture, which already has to manage extreme climatic variability, is one of the more vulnerable sectors in Australia. As the reality of climate change is being increasingly accepted, attention is rapidly shifting from describing the likely impacts of climate change to addressing the challenges of adaptation. There are many potential incremental adaptation options available to offset projected impacts.

However, it has been suggested that even well planned incremental innovation will not be a sufficient response to some of the future projected climate changes that the agriculture sector is likely to face over the coming decades.

Several studies have concluded that more transformational change will be required in some cases.[38]

CSIRO's work on climate ready crops is one such attempt to develop the approaches that will be required to bring about transformational change in Australian agriculture. This CSIRO research project aims to develop the options for crops to be planted beyond 2025. CSIRO have argued this level of forward planning is relatively unprecedented in Australian agriculture.

E.7.2 CSIRO research

Most stakeholders would probably identify a shortage of water as the key challenge facing agriculture in the future. Certainly, there is considerable Australian and international research under way to address this particular risk by developing drought tolerant crops. However, the CSIRO Climate Ready Crops research is more about identifying and capturing the opportunities that might result from the impacts of climate change. Specifically, crops that can better cope with high temperature events and also are suited to, and capable of extracting extra productive value from, higher levels of CO_2 in the atmosphere. The initial focus of the research is on wheat.

Wheat was selected as it is Australia's largest grains crop and one of the largest Australian export crops, with export earnings of $4.75 billion in 2009.[39] Wheat is also relatively susceptible to high temperature events. For example, in South Australia there was a 30% drop in wheat yield following an extreme temperature event in 2009 – with such events likely to become more frequent and widespread in coming years.

There are four elements to the CSIRO research:

- Research supported under the Department of Agriculture, Forestry and Fisheries (DAFF) under the Australian Farming Futures Fund that is intended to establish an understanding of what genetic traits are needed to withstand higher temperatures and CO_2 levels and then identify plants with those genetic traits

[38] For example, Easterling W., Aggarwal P., Batima P., Brander K., Erda L., Howden M., Kirilenko A., Morton J., Soussana J-F., Schmidhuber J., Tubiello F. (2007). Climate Change 2007: Impacts, Adaptation and Vulnerability. (Eds. Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE), pp273-313, (Cambridge Univ Press, Cambridge, UK) and Howden, S.M., Soussana, J.F., Tubiello, F.N., Chhetri, N., Dunlop, M., and Meinke, H.M. (2007). Adapting agriculture to climate change. Proceedings of the National Academy of Sciences, 104:19691-19696.

[39] Exports of Primary and Manufactured Products Australia, Department of Foreign Affairs and Trade June 2010

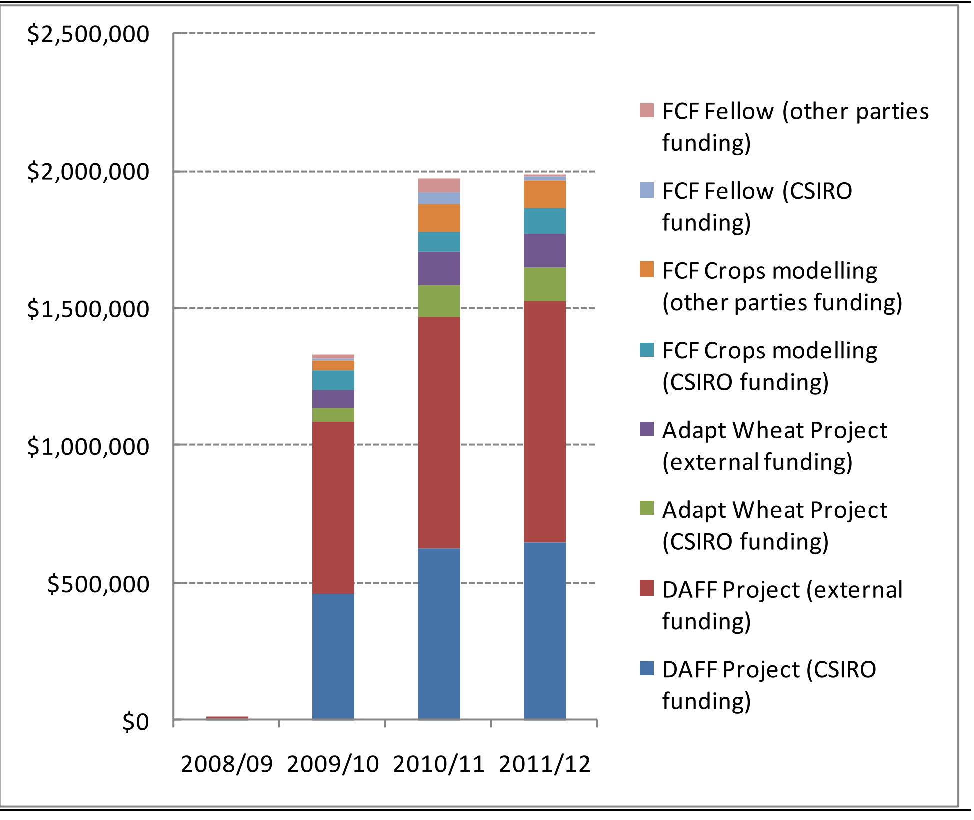
- The Grains Research and Development Corporation (GRDC) is supporting work that is complementary to the work mentioned in the previous dot point, including scanning wheat gene banks
- A flagship collaboration fund project with the University of Queensland that is using the results from the above two components as inputs into crop models to determine potential yields and growing locations
- A further flagship collaboration fund project to bring an Argentinean researcher to Australia to support research into the impacts of higher temperatures on wheat yields.

E.7.3 Cost of the research

The total cost of the research effort is just under $5.3 million over the period 2008/09 to 2011/12. Figure E9 shows the expenditure over time on the various components of the climate ready crops project.

The NPV of the total climate ready crops program is $4.3 million.

Figure E9 **Cost of CSIRO research on climate ready crops**



Source: CSIRO personal communication May 2010

E.7.4 Benefits of the research

CSIRO has estimated that the climate ready crops research could lead to a 5-10% improvement in yield compared to a business as usual approach. They have estimated that the probability of success of the project is between 8 and 14%.

If the project is successful then the CSIRO estimates that seed supplies of the new wheat variety would be available within as little as 8 years, but it is more likely to take closer to 12 years; this would seem broadly in line with historical experience in plant breeding. Take up rates in Australia for new varieties of crops are relatively rapid, particularly when there are demonstrated yield benefits. CSIRO estimate that the total take up rate would be between 50% and 70% within 5 years.

To calculate the potential NPV of the improved wheat varieties we have assumed that;

- annual production of wheat is steady at the average for the last ten years a
- 80% of the crop is exported
- The average loss in yield due to heat stress is 5%
- the new varieties of wheat are available by 2022
- the take up rate of the new varieties is 15% a year up to a maximum of 60%
- the new wheat is less sensitive to heat stress and also has an improvement in yield of 5% due to its ability to utilise the higher CO_2 content in the atmosphere
- the discount rate is 7%
- the price of wheat remains constant at$200/tonne in real terms

With these assumptions, the difference in the NPV of wheat exports between 2010 and 2050 is almost $1.1 billion.

E.7.5 The counterfactual

We understand that the current main focus of overseas research is to develop drought tolerant wheat varieties. However, the CSIRO project is the first in the world to try to develop new wheat varieties that are temperature tolerant and better able to deal with higher concentrations of CO_2 in the atmosphere.

We have estimated that, in the absence of the CSIRO work being done, the delivery of the new seed varieties would be delayed by some 8 to 12 years. Large international seed companies could potentially be the fastest to catch up due to the significant financial resources that they could bring to bear on the research task.

CSIRO argues that if the new varieties where developed overseas then their availability might be restricted in Australia as overseas seed companies are likely to supply their overseas markets before Australia. Furthermore the CSIRO expects that the licence fees that Australian farmers would need to pay to access the new wheat varieties would be higher if international seed companies had developed the new variety.

If we assume that an overseas developed variety of wheat with the same properties as the potential CSIRO wheat strain is developed eight years later (i.e. by 2030 rather than 2022) and that all other assumptions still hold then while there is still an improvement in the NPV of wheat exports between 2010 and 2050, however it is some $500 million less than if had been developed by the CSIRO.

This is significantly more than the $5.3 million cost of the Climate Ready Crops research by CSIRO.

E.8 Emerging risks/issues

The Climate Adaptation Flagship sees the following as being some of the key areas where it will be focusing its future efforts:

- Ensuring that Australia's population is prepared for adaptation through facilitating behavioural change and building adaptive capacity
- Designing cities and infrastructure to adapt to rising sea level, coastal inundation and increasing population
- The need for information about climate change impacts at the regional and local level
- Better adapting to extreme events (storms, heatwaves, bushfire, drought)
- How to manage Australia's marine and terrestrial species, ecosystems under climate change, including exploring novel strategies e.g. assisted migration
- Major changes to agricultural systems and communities due to changes in climate

The Flagship is also expected to be an integral part of the proposed Australian Integrated Carbon Assessment System (AICAS). AICAS is discussed further in SectionP.

F Aquaculture prawn breeding and novel aquaculture feeds

F.1 Key points

F.1.1 Immediate impacts

Breeding

- A demonstrated threefold increase in farmed prawn production on one commercial prawn farm
- Two other prawn farms are now using 2^{nd} and 3^{rd} generation domesticated stock
- High prospects of extending the performance of elite stock up to 10 times current industry averages
- Significant reduction in cost of production of farmed prawns which will lead to a change in the relative price of farmed verses wild catch prawns
- A potential increase in net value of prawn production, based on growth rates alone, in Australia of approximately $430m dollars (present value)

Novel feeds

- The development of a novel bioactive feed ingredient that increases prawn growth rates by 50 per cent compared to current feeds
- As the novel bioactive feed ingredient is based on agricultural waste streams, future prawn feeds are likely to reduce the need for raw materials to be sourced from wild catch 'industrial' fish resources
- The establishment of a novel bioactive feed ingredient industry in Australian with a gross value of up to $21m (present value).
- Increased value of prawn production estimated at $84m (present value)
- Domestic royalties of approximately $1.0m (present value)
- Substantial international royalties

F.1.2 Potential longer term

There are a number of longer term potential benefits of both the breeding technology and novel feeds innovations. While they have not been quantified in this case study they have been qualitatively presented. They are based on discussions with CSIRO, and fisheries economic theory:

- If both the innovative breeding process and novel feeds are applied to a range of other species the potential benefits (economic, social and environmental) are substantial. If the technology is successfully applied to other farmed species it is likely to reduce the cost of production significantly, increase quality, and reduce reliance on wild stocks. At this stage CSIRO believes that this technology can be applied to other species. Trials of the breeding program are already underway with salmonid species (Preston, per comm. Everingham 2005)

- Over time, and if widely adopted in Australia and overseas, the innovations combined are likely to alter the relative prices between farmed and wild catch as farmed prawns become cheaper to produce domestically and internationally. This change in relative prices will reduce the incentives to continue to fish depleted fisheries, reducing the economic losses of inefficient fishing effort
- The increase in production and the development of novel feeds will significantly increase the policy levers that governments will have to manage fisheries
- Creates an option to continue to provide animal protein for human consumption should climate change detrimentally affect wild caught fish stocks and terrestrial livestock production
  - The area that could be developed for prawn farming in Australian is extensive and able to be chosen to exploit saline water resources and sited to reduce climate change risks

F.2 Background

This case study analyses the impact of CSIRO's new prawn breeding and genetic selection techniques, and the development of an aquaculture novel bioactive feed ingredient. However, as with many CSIRO outputs identified in this study, the principle subject is an example of one specific output (with direct commercial application) of a significant body of research in this case into animal breeding management and protein for human consumption.

The prawn breeding and novel bioactive feed ingredient projects are formally part of CSIRO's future animal breeds and nutrition theme administered under the Food Futures Flagship.

However, to fully capture the context of the prawn breeding and novel feed ingredient innovations they should be characterised as being part of several CSIRO portfolios that are broader than the Food Futures Flagship within which they currently sit:

- These innovations could be seen as part of CSIRO's fisheries resource management portfolio which spans aquaculture and fisheries resource management
- These innovations also form part of the suite of investments CSIRO has made in human nutrition (in particular protein production for human consumption) which includes terrestrial protein production such as

livestock, grains and pulses. This is a further demonstration of the multidisciplinary capability that CSIRO applies to major areas of national interest and risk.

- The objectives set for the theme of which prawn breeding and novel feed ingredients are part, clearly demonstrates the scale and scope of the role that CSIRO plays in the national innovations system and national risk management. The theme's objectives are:
  - to achieve a quantum increase in the value of Australia's livestock industries, with a particular emphasis on the cattle industry
  - to transform the productivity, profitability and sustainability of Australia's Atlantic salmon, abalone, oyster and prawn farming industries
  - to create a new aquafeeds ingredient industry based on the bio-conversion of agriculture plant wastes that will reduce global reliance on wild-harvest fishmeal
- These objectives are translated into a series of outputs that the theme's performance is measured against:
  - Annual value of Australia's beef and dairy herds increased by up to $1.3 billion via the use of novel stem cell and proteomics technologies that fundamentally alter the delivery of livestock genetics and accelerate the rate of genetic gain
  - Enhanced nutritional value of animal products via increased micronutrient and beneficial fatty acid content without reducing production efficiency
  - Annual value of Australian farmed fish, crustaceans and molluscs increased by up to $930 million via the development and adoption of elite, high-health genotypes and advanced selective breeding technologies
  - Agriculture plant wastes successfully converted to high value animal feed ingredients, creating a new $300 million Australian industry and reducing global reliance on wild-harvest fishmeal
  - Feed conversion efficiency in marine aquaculture systems improved by 20% via the adoption of novel sensor based feeding technology
  - CSIRO at the forefront of global knowledge and technology in testis cell transfer, advanced animal genetics and breeding and novel feed production and delivery (CSIRO, *perpers comm*)

However, these outputs, assuming they are achieved, could have far more significant global impacts by:

- Reducing the costs of animal protein sources and addressing just concerns in global food production
- Significantly reducing the relative cost differential between farmed and wild-catch marine species

- Reducing exposure to risks of rising oil prices etc
- Creating of options to limit threats to some species
- Fully domesticating the production of a range of currently farmed aquaculture species and the production of aquaculture feeds
  - Making it economically viable to farm a range of marine species currently not farmed

The likely sources of value of this theme are:

- Commercial:
  - Royalties, joint venture or sale of intellectual property associated with the breeding processes and novel feeds production. The commercial value of this IP would be based on:
    - … The reduction in the cost of production of the technology (breeding and novel bioactive feed ingredients)
    - … Any prawn quality improvements such as colouration, eating quality, etc that leads to a the achievement of a price premium
- Contributions to the domestic economy:
  - Considerable increase in prawn and aquaculture productivity
  - Replacement of seafood imports
  - Increased seafood exports
  - Sale of elite breed stock and IP overseas. However, IP may be difficult to protect as this innovation uses readily available technology in innovative ways (current research includes developing methods of producing sterile prawn seedstock to prevent unlicensed breeding of the elite genotypes)
  - Potentially substantial reduction in the economic losses (the economic cost of wild catch stocks being fished at maximum sustainable yield (MSY) rather than sustainable economic yield (MEY)) by reducing the costs of farmed prawns relative to wild catch and altering incentives to fish wild stocks
- Broader economic value:
  - Increased consumer surplus from a reduction in the cost of animal proteins for human consumption
  - Improved management of Australia's wild catch fisheries resources by reducing the relative value of farmed seafood compared to wild catch prawns of similar quality. This potentially could lead to consumers switching to farmed prawns (and other species as the technology is applied) reducing the demand for wild catch

- Risk management:
  - Provide a potential source of adaptation for seafood production in response to climate change impact on wild catch fisheries, and potential changes to terrestrial animal production

These potential sources of value cannot simply be aggregated, and care must be taken not to qualitatively or quantitatively double count some of the benefits.

There are environmental costs that need to be deducted from the benefits listed in the previous dot points. Wastes from aquaculture cage-farms have a demonstrated minimal effect on the local ocean environment in which they are located, and land based ponds produce wastes. However, in relation to land based aquaculture wastes can be captured using bioremediation technologies, mitigating the need for wastes to be disposed of (CSIRO research advances have placed Australia at the global forefront of pond discharge treatment, recapture of nutrients and environmental management).

Another cost of current aquaculture farms is the use of wild catch recruitment stock that depletes marine resources. However, these costs are largely avoided by domesticating the breeding and replacing a proportion of wild caught with non-marine feed sources.

F.3 The innovation

The breeding innovation that is the focus of this case study is the combination of the application of several technologies to black tiger prawn breeding. Some other prawn (shrimp) varieties have achieved considerable genetic performance improvements.

The component black tiger prawn breeding innovations can be summarised as:

- Achieving genetic gains using selection strategies that allow unbiased expression of the genetic performance for key traits, and exploiting the broad levels of genetic diversity
- Employing genetic markers to enable optimal selections of the elite stock
- Efficient propagation of the elite stock
- Repeating the breeding cycle without drawing stock from the wild
  - The distribution curve of performance of each generation, when elite stock from the previous generation is used, shifts to the right. This allows a new elite sample to be identified and forms the breeding stock for the next generation. This is standard genetic selection theory but has been applied to black tiger prawns for the first time

CSIRO describe the breeding innovation as:

Implementation of genetic technologies and approaches to enable rapid genetic and economic gains given biological and practical constraints specific to the industry.

Prawns produce a massive amount of offspring per individual mating (up 500,000 larvae) and the generation interval is short. This means that substantial genetic selection pressure can be applied through intensive selection repeated over shorter production cycles.

The genetic science applied to the prawn breeding program is well established in terrestrial domestic animals such as sheep and cattle. However, the selection pressure able to be applied to domestic terrestrial animals is limited by the annual breeding cycle and the low number of progeny per breeding pair produced in each cycle.

Some previous black tiger prawn breeding programs have failed to allow the full genetic potential to be expressed by successive populations which has restricted the ability to identify elite stock. This failure to allow full genetic potential to be expressed appears to be due to several reasons:

- A failure to identify and control for a range of phenotypic constraints
- Once higher performing prawn were identified, physical tagging techniques meant that single families had to be bred and the progeny grown out in isolation. This exposed the families to variations in phenotypic influences and confounded the identification of genetic performance.
- A generic principle in achieving genetic performance improvements is separating phenotypic and genotypic effects. By using genetic markers CSIRO has reduced phenotypic influences by allowing family to breed in the same pond and are therefore subject to the same environmental influences.
- The extent to which environmental effects can mask genetic performance when families of prawns (or any other animal) are physically separated to ensure pedigrees can be established is reported in a recent article in the Global Aquaculture Advocate.
  - The article presented the results of research into the tank effects on selection responses in shrimp breeding (Rocha, Guerrelhas, Teixeira, Farias, & Teixiera, 2010).
  - The research analysed the variation in tank effect on single shrimp families and found that as much as 0.01 to 3.4 per cent of total variance, 1.10 to 30.40 per cent of the genetic variance, and from 2.20 to 37.80 per cent of the full-sib family variance. The results of this research are found in below.

Table F1 **Aggregate larviculture and juvenile rearing tank effects on shrimp growout traits (variance components)**

	Genetic nucleus performance test			Field pond performance test		
	Harvest weight	Weekly growth	Survival	Harvest weight	Weekly growth	Survival
Tank variance	0.1169g^2	0.001320(g/week)^2	5.47E-06	0.2205g^2	0.004807(g/week)^2	0.001194
Genetic variance	0.8894g^2	0.009696(g/week)^2	0.000478	0.7258g^2	0.016392(g/week)^2	0.009456
Tank/genetic variance	13.1%	13.6%	1.1%	30.4%	29.3%	12.6%
Tank/full –sib family variance	20.8%	21.4%	2.2%	37.8%	37.0%	20.2%
Tank P value	0	0	0.0021700	0.0004780	0.0005920	0.0000394

Data sourcet (Rocha, Guerrelhas, Teixeira, Farias, & Teixiera, 2010)

Table F2 **Reduction in selection response determined by detected tank effects under current program design and parameters (theoretical estimate)**

Genetic nucleus traits		Field commercial pond traits	
Harvest weight	Test weekly growth	Harvest weight	Test weekly growth
14.4%	14.5%	33.8%	32.7%

Data source: (Rocha, Guerrelhas, Teixeira, Farias, & Teixiera, 2010)

F.4 Counter factual

The fact that this black tiger prawn research relies on the application of existing genetic selection and bio-processing technology in a unique way (allowing the novel feeds technology to be patented) suggests that it is likely that if CSIRO had not invested this research it would have been developed by someone else at a later date. That is CSIRO can claim to have brought forward the innovation (although possibly quite significantly).

It is estimated by CSIRO that the average annual growth rate improvement using tradition breeding and genetic selection technologies is approximately 10 per cent (Preston, per comm.). This is dependent on using farmed seed stock. Annual use of wild catch broodstock to generate the larvae to stock farms is unlikely to produce any increase in growth rate. However, more than 90 per cent of Australian prawn farms currently stock their farms with wild caught larvae and therefore make not genetic gains.

Data in Table F3 shows the comparative genetic gains from the high, average and low results of CSIRO's eighth generation of elite prawns (based on full size commercial applications assuming an average of 4.5t/ha prior to commencement of the breeding program. The right hand column in the table shows the estimated rate of improvement where existing breeding and genetic selection technologies are used on domestically bred breeding stock. However, as noted earlier most of the Australian prawn farms use wild catch breeding stock annually where no genetic gain is made.

Table F3 **Comparative genetic gain**

	CSIRO average improvement per generation			
	High	Average	Low	**Growth rate likely to be achieved by domesticate breeding process**
	kg/ha	kg/ha	Kg/ha	kg/ha
Generation	23.30%	18.50%	15.40%	10%
1	4500	4500	4500	4500
2	6841	6319	5993	5445
3	8435	7488	6916	5990
4	10401	8873	7981	6588
5	12824	10515	9210	7247
6	15812	12460	10628	7972
7	19496	14765	12265	8769
8	24039	17497	14153	9646
9				10611
10				11672
11				12839
12				14123
13				15535
14				17089
15				18798
16				
17				
18				
19				
20				
21				

F.5 Additionality or why is CSIRO investing in prawn breeding and novel aquaculture feeds research?

With potentially large private benefits able to be derived from this technology what was the rationale for CSIRO to invest in these projects? This question will require more analysis to answer, but it appears that:

- Wild stocks of prawns are possibly underpriced from a society perspective and therefore there are reduced incentives for prawn farmers to invest in this technology:
  - This may mean that CSIRO brought forward the innovation as it may have been developed if the constraints on the harvesting of wild stocks increased
- Wild catch aquaculture feed sources may also be similarly underpriced

Few other private organisations have the multidisciplinary capability to cost effectively form a team that would apply the same combination of terrestrial genetics and aquatic/aquaculture.

Even if there are sufficient benefits that can be captured by private investors to justify the investment, it may not have been for some time before this technology would have been developed by private interests. However, there are significant social and environmental benefits that can be gained by investing early.

Also CSIRO has also been investing with some success in conjunction with other private and public interests to improve the management of Australia's prawn fisheries most of which are under stress. The fishing effort in the prawn fishery is generally considered to be highly profitable, all of which reduces the incentive to invest in improving aquaculture production.

F.6 Current status

The prawn breeding trials have completed their eighth generation where significant genetic progress has been quantified. A number of novel feed trials have been undertaken and significant increases in growth rates have been recorded. In 2009 one commercial partner used elite breeding stock to stock all of it 50 ha of aquaculture ponds for the first time (that is no wild catch breeding stock were used). There are two other prawn farms currently using 2nd and 3rd generation elite stock and appear on track to produce similar production gains.

The farm that stocked all of it 50 ha of ponds for the first time in 2009 recently completed its 2010 harvest in May. This harvest produced a total of 875 tonnes of prawns averaging 17.5 tonnes per ha. 14 of the prawn ponds exceeded 20 tonnes per ha. One pond set a new record for the farm of 24.2 tonnes per ha.

This level of production was achieved with a feed conversion ratio of 1.44 (1.44 kg of feed per kg of prawn produced) and an average weight of 37 grams per prawn[40].

According to the Australian Seafood Cooperative Research Centre the average prawn yield per ha of aquaculture pond is over 4.5 tonnes per ha (Australian Seafood CRC, 2010). The average yield achieved by CSIRO's commercial partner is 437.5 per cent of the current national average per ha yield.

Based on the growth rate distribution observed in the elite farmed prawn population, the theme leader, Nigel Preston, believes that yields of 40 tonnes per ha is achievable from the integration of the elite breeding program stocks with continued improvements in on-farm production and harvesting technologies

The breeding innovations appear to be able to be applied to a wide range of species currently farmed, and provide the opportunity to farm a range of species that are currently supplied exclusively from wild stocks.

F.7 Commercialisation

There are negotiations underway with an Australian company to commercialise the breeding and genetic selection processes. However, the breeding innovations IP are unable to be protected until seed stock sterilisation techniques have been achieved, research which is currently underway by CSIRO. The dissemination of the innovation will in the first instance be through the sale of breeding stock to other farmers from those working with CSIRO at present, although this will be entirely driven by the firms involved in the breeding research..

Eventually other domestic and international aquaculture businesses will adopt the innovation to develop their own elite stock, possibly based on a range of traits aligned with particular production systems and markets. However, the Australian producers will maintain 8 generations of selection as an advantage for some time.

There are also negotiations underway with an Australian company to commercialise the novel bioactive feed ingredient production process. CSIRO

[40] Extracted from a letter from General Manager of CSIRO's commercial partner to Nigel Preston, theme leader prawn breeding and novel aquaculture feeds

expects to be able to charge a royalty of between 4 and 6 per cent of the ex-works price of the feed novel bioactive feed ingredient.

F.8 Research Origins

There are discrete capabilities that contribute to this case study. These innovations when applied to prawn aquaculture are additive but draw on three distinct capabilities:

- Biology of marine species
- Genetic selection techniques similar to those used in livestock genetics and performance selection techniques
- Novel marine microbial bioconversion processes (applied to agricultural carbon based wastes such as rice husks, pea shells, and other processing by products)
- The breeding novel bioactive feed ingredient themes draws from a range of CSIRO and external capabilities which can be seen in the data in Table F3and Table F4.

Table F4 **Capabilities used in the aquaculture breeds stream**

Division	FTE	Capabilities
CSIRO MAR	16.35	reproductive biology, embryology, molecular genetics, quantitative genetics, genomics
CSIRO LI	4.7	quantitative genetics, bioinformatics, molecular virology and immunology
FSA	0.6	food chemistry, biochemistry
CSIRO MIS	0.8	statistics
UTAS	3	PhD Students
UQ	1	Invertebrate molecular embryology
Flinders U	3	PhD students, molecular biology, chromosome manipulation
Total	29.45	

Data source: *(Preston, 2010)*

Table F5 **Capabilities used in the feedsfeed technologies stream**

Division	FTE	Capabilities
CSIRO MAR	5	animal nutrition, biochemistry, aquaculture biology, microbiology, molecular genetics, nutrigenomics
ICT	2.0	sensor based feed technology
FSA	0.9	food technology, chemical engineering, bioactive separation
CSIRO LI	1.15	Cell culture, bioactive separation, protein chemistry
CSIRO PI	0.1	starch chemistry
Total	89.15	

Data source: *(Preston, 2010)*

These capabilities have been separately applied to a number of other aquaculture and terrestrial animal industries, and at times have resulted in a range of new innovations for these industries.

The prawn breeding and novel bioactive feed ingredient innovations analysed in this case study appear to be the result of the application of a series of well known techniques to a novel situation. The fundament innovations appear to be able to be summarised as:

- Researching prawn aquaculture biology that has allowed a process to be developed where the genetic potential of prawns can be expressed (in this case growth rate) so that high performing stock can be identified.
- The use of genetic markers to identify and monitor selected prawn stocks, where previously physical identification methods were exclusively relied on
- The application of conversion novel marine microbial bioconversion methods to be applied to a range of agricultural by product feed stocks to enable the production of a protein enriched bioactive feed ingredient.

F.9 Key benefits emerging from the work

The impacts of this research work appear to be substantial both in the domestic market and the international aquaculture market of which Australia is a tiny participant.

Table F6 **CSIRO's own contribution estimates (forecast gross sales increase estimates or cost savings $'000)**

Theme	Stream	2013 conservative	2013 optimistic	Mature conservative	Mature optimistic
2. Breed Engineering	2B. Engineering Aquaculture Breeds	373.0	829.9	376.0	842.7

Data source: CSIRO

In 2005 CSIRO conducted a high level impact assessment of the animal breeding and novel feeds theme. The results of these high level analyses are reproduced in Table F6. They include the application of the breeding technology to several other species including salmon. While great care should be exercised with making impact assessments from the results in Table F6, they at least provide a guide to the potential quantum of the industries involved and the scope of the work being undertaken.

At present, the average per ha farmed prawn yield has been approximately 4 - 4.5 tonnes per ha. As discussed, the breeding innovations are well advanced and being proven at commercial farm scales. These yield increases have been achieved 5 years earlier than anticipated at the start of this project.

It is anticipated, based on identified elite prawns and improvements to some aspects of farming operations, that future generations will be able to achieve 40tonnes per ha..

These yields convert to huge increases in gross income per ha. This yield increase can be achieved with little or no increase in overhead costs, and only modest increases in direct costs—mostly involving increased feed costs to support increased growth rates.

Trials are currently underway to improve Atlantic salmon yields also. It is also possible to apply this process to achieve genetic gains in other traits such as taste, and disease resistance.

It appears that the farmed prawns are at least equal in eating quality if recent taste test comparisons and competition results are a guide. Given that a range of quality traits, such as colour can also be selected for, it is also possible that a premium over wild catch prawns may be achievable.

The novel bioactive feed ingredient developed has increased black tiger prawn growth rates by 54 percent.

While the private benefits derived by these productivity gains are likely to be significant there are at least equal, if not significantly larger spillover benefits. These are likely to be in areas such as:

- Reduced reliance on wild catch feed sources estimated to be approximately 30million tones per annum world wide
- This technology is likely to have impacts well beyond the domestic industry which produces only 3,000 to 4,000tonnes tonnes of the 4,000,000tonnes of farmed prawns produced annually worldwide.

These opportunities offer the ability to significantly change the portfolio balance of fisheries resource management by dramatically increasing aquaculture production, and lowering per unit costs.

F.9.1 Industry benefits

The industry benefits of this technology are proving to be significant. As discussed one of CSIRO's commercial partners has harvested the eighth generation of elite prawns and achieved yields up to 5 times the industry average per ha. This has been achieved at a feed conversion rate (kg of feed required to produce a kg of prawns) of 1.44. CSIRO's commercial partner has not used the novel bioactive feed ingredient as yet.

Table F7 **Cost of production of a kg of prawns to changes in yield and feed conversion**

Average kg per ha harvested	1 .00 kg feed/kg prawns	1.25 kg feed/kg prawns	1.44 kg feed/kg prawns	1.50 kg feed/kg prawn
2000	13.057	13.5427	13.912	14.0286
3000	10.176	10.662	11.0313	11.1479
4000	8.7358	9.22172	9.59103	9.70765
4500	8.25568	8.7416	**9.11091**	9.22753
5000	7.8716	8.35751	8.72681	8.84344
6000	7.2954	7.78132	8.15062	8.26725
7000	6.8839	7.36983	7.73914	7.85576
8000	6.5753	7.06118	7.43049	7.54711
9000	6.3352	6.82113	7.19043	7.30705
10000	6.1432	6.6291	6.99841	7.11503
11000	5.986	6.47195	6.84125	6.95787
12000	5.8551	6.341	6.71031	6.82693
13000	5.7443	6.23023	6.59953	6.71616
14000	5.6493	6.135266	6.50456	6.62119
15000	5.567	6.05295	6.42226	6.53888
16000	5.495	5.98095	6.35025	6.4688
17000	5.4315	5.91739	6.28669	6.40331
17500	5.40241	5.88834	**6.25764**	6.37426
18000	5.375	5.8609	6.23021	6.34683
19000	5.3244	5.81037	6.17968	6.29663
20000	5.27896	5.76489	6.13419	6.25082

Data source: ACIL Tasman using the Prawn Profit calculator (Q DPI)

The sensitivity analysis in Table F7 uses the Prawn Profit calculator developed by Bill Johnston, a fisheries economist at the Queensland Department of Primary Industries to calculate the cost of production of a kg of prawns to changes in yield and feed conversion for a 50 ha prawn farm. The 8th generation results from CSIRO commercial partner are highlighted in green.

The increase in yield from the CSIRO breeding program has reduced the cost of production for a 50 ha farm (based on the QDPI model) from $9.11 per kg to $6.26 per kg. This is a 31 per cent reduction in the cost of production. Some of the reduced costs will be shared, over time through changes in the cost of breeding stock and larvae, with the elite stock producers. That is, while the elite stock producers are likely to command a significant premium for larvae in the short term, over time this premium will be reduced as competitors enter the market with their own elite stock.

Based in this reduction of the cost of production it is likely that the considerable portion of the Australian wild caught and prawns imported into Australian would be substituted with Australian aquaculture prawns as the domestic product becomes more cost competitive. The current value of imported prawns averaged $204m from 2005-06 and 2007-08 (see Table F8) (ABARE, 2009).

Table F8 **Australian prawn production and trade**

	2005-06		2006-07		2007-08	
	t	$'000	t	$'000	t	$'000
Australian Wild catch prawns	20046	255040	17490	22232	19342	223339
Australian farmed prawns	3541	49727	3284	45120	3088	44203
Total prawns	23587	304767	20774	67352	22430	267542
Exports	8744	133923	6376	93563	4916	68624
Imports	23165	201351	26016	246387	18731	166646
Net trade balance	-14421	-67428	-19640	-152824	-13815	-98022
Total non Australian farmed prawns consumed in Australia	34468	456391	43506	268619	38073	389985

Data source: (ABARE, 2009)

However, this market share would only be sustained until international farmed prawn competitors adopted the technology and/or made significant other productivity gains.

The tables below depict the increase in net revenue of the increase in prawn production likely from the adoption of the technology through the use of elite breeding stock. It assumes an adoption rate of the new technology of 18 per cent per annum.

Other major assumptions used in the modelling are:

- The calculations also assumes an small increase in prawn farm area, based on current industry projections, however, with the level of added production from the CSIRO breeding program, it is likely that additional prawn farm ha would be added or at least commenced over this period
- Elite stocks are expected to increase in genetic growth rate potential at the current level of average improvement of 18.5 per cent per annum
- Modelling also assumes that the IP is difficult to protect and/or elite prawn stock would be purchased by overseas competitors and would enter breeding programs. However, to improve IP protection CSIRO is also

researching how elite stock can be made sterile so the elite genetics can be protected.

- This modelling also assumes that the 3 farms currently partnering with CSIRO in the breeding program will sell larvae to other Australian farms rather than retain the stock for exclusive use
- The modelling only extends to the expected full adoption of the elite stock which occurs in 2016. After this time international competitors could be widely using this or similar technology and the additional prawns being produced would affect international prawn prices. It is possible that the benefits of the technology for the Australian industry would continue but slowly decline after 2016. However, this is a conservative approach given that as stated Australian prawn farmers have an 8 generation lead, and second CSIRO is researching ways to sterilize elite genotypes to prevent unlicensed breeding
- Prawn growth rates will improve by 50 per cent if the novel feeds are used. Advice from CSIRO suggests that the feed price is expected to be 50 per cent higher than current feeds
- Once the international prawn industry adopted or replicated the technology the Australia industry would begin to lose its competitive advantage. The benefits of this technology would also accrue to consumers through lower prices for prawns, improved fisheries management options, and a drop in the price of animal protein for human consumption. Many of these benefits are discussed in more detail in section F.9.3.

The results of the modelling are presented in Table F9. They should be considered as high level lower bound returns. They do not show the potential sales of the technology, expertise or seed stock to overseas prawn farmers, revenues from which could be considerable. Such sales could possibly detract, in time, from local returns – but we have assumed the technology could not be controlled indefinitely. The commercial advantaged is underscored more by the lead time now established as a result of CSIRO's involvement.

Using a 7 per cent real discount rate the increased production produced from the use of elite breeding stock could be as high as $430m.

Table F9 **Estimated additional prawn production and value form adoption of elite breeding stock**

Year		2010	2011	2012	2013	2014	2015	2016
Total prawn farm area			875	900	925	950	975	1000
Area of prawn production adopting new elite varieties	ha		160	182.5	365	547.5	730	912.5
Additional prawn produced	t		2103	3193	7568	13452	21254	31482
Gross value of prawns			$ 34,700,122	$52,687,323	$124,868,955	$221,954,567	$350,688,215	$519,456,919
Cost of production			$13,165,016	$19,989,251	$ 47,374,525	$84,208,217	$133,048,984	$197,078,807
Net addition revenue		$809,491,301	$21,535,106	$32,698,072	$77,494,430	$137,746,349	$217,639,232	$322,378,112
PV	4%	$ 671,240,150	$20,706,833	$30,231,205	$68,892,266	$117,746,157	$178,883,584	$254,780,105
PV	7%	$489,134,140	$19,352,180	$26,405,106	$56,236,611	$89,827,979	$127,541,523	$169,770,742
PV	10%	$318,044,818	$17,592,891	$21,822,401	$ 42,251,398	$61,353,718	$ 79,193,251	$95,831,158
Production that would otherwise have occurred			720	821	1643	2464	3285	4106
Gross value			$11,880,000	$13,550,625	$27,101,250	$40,651,875	$ 54,202,500	$ 67,753,125
Less cost of production			$6,559,200	$7,481,588	$14,963,175	$22,444,763	$ 29,926,350	$ 37,407,938
Net farm value		$96,356,363	$5,320,800	$6,069,038	$12,138,075	$18,207,113	$ 24,276,150	$ 30,345,188
PV	4%	$81,017,009	$5,116,154	$5,611,166	$10,790,704	$15,563,516	$ 19,953,226	$ 23,982,242
PV	7%	$60,570,978	$4,781,452	$4,901,010	$8,808,429	$11,873,332	$ 14,226,374	$ 15,980,381
PV	10%	$40,978,712	$4,346,775	$4,050,421	$6,617,903	$8,109,645	$ 8,833,459	$ 9,020,508
Net increase in prawn farm gate value		$713,134,939	$16,214,306	$26,629,034	$65,356,355	$119,539,237	$93,363,082	$292,032,925
PV	4%	**$590,223,141**	$15,590,679	$24,620,039	$58,101,562	$102,182,641	$58,930,358	$230,797,862
PV	7%	**$428,563,162**	$14,570,728	$21,504,096	$47,428,181	$ 77,954,647	$13,315,149	$153,790,361
PV	10%	**$277,066,105**	$13,246,116	$17,771,980	$35,633,495	$53,244,073	$70,359,792	$86,810,649

Data source: ACIL Tasman

This model is highly sensitive to the rate of adoption, which as noted is dependent on the current commercial breeding program partners selling elite stock to other Australian farms. However, while this is a commercial decision there are likely to be strong incentives for the current farms to sell elite larvae at a premium rather than grow them out for commercial production. A sensitivity analysis to adoption rates is included in Table F10:

Table F10 **Sensitivity to adoption rate (million)**

	Adoption rate pa		
	10%	18%	22%
Discount rate			
4%	$370	$590	$700
7%	$270	$430	$510
10%	$176	$280	$330

Data source: ACIL Tasman

CSIRO does not believe that significant royalties or other IP charges will come from the breeding program, given the difficulty of protecting IP at this stage. However, as the technology is progressively rolled out, CSIRO does expect to be able to charge for ongoing services supporting the adoption of the technology.

F.9.2 Novel feeds

The value of novel feeds will be realized in several ways:

- 50 per cent increase prawn growth rate
- Potential increase in value of the agriculture waste products used to manufacture the novel feeds
- Potential replacement of wild catch feed sources over time
- An additional policy lever (wild catch feeds could be constrained further as alternative feed sources are available)
- Exporting the supplement to overseas prawn farms
- Adaptation of the feed to other feed sources

Advice from CSIRO suggests that the price of the novel bioactive feed ingredient will be approximately $3000 per tonne which is a 50 per cent increase on the current price of wild catch based fish meals. However, prawn farmers will increase production of prawns by 50 per cent if the ration is made up of 10 per cent novel feed supplement. At $16.50 per kg for prawns at the farm gate this means an increase in gross revenue of $37,125 per ha. The additional feed costs (based on $3000 per tonne of novel fed added at 10 per cent) would be $7452 per ha (includes addition feed at higher cost).

The net gain for the farmer using the novel feed per ha is approximately $29,700 per ha.

CSIRO expects to be able to charge a royalty of between 4 and 6 per cent of the ex-works value of the feed. Based on this royalty and anticipated adoption rate of 30 per cent per annum, CSIRO would recoup $744k in the first 5 years of adoption of the novel feed technology. Assuming that the revenues from the royalties remain constant for another 10 years at this level the total present value of the domestic royalties at 7 per cent discount is $2.8m. If CSIRO achieves only a fraction of the market share it achieves in Australia in the international market, revenues could be approximately $14m (based on CSIRO estimates).

The ability to achieve international feed market share is supported by at least one licensing agreement (in final stages of negotiation) with a large international prawn farm (alone several times the size of Australia's current total production) and several other preliminary opportunities are being evaluated.

Table F11 **Estimated value of novel feed ingredient (combined with expected increase in prawn production from adoption of breeding techniques)**

Year				2012	2013	2014	2015	2016	2017-2026
Total aquaculture prawns produced	t			6422	10088	15263	22356	31876	
Total feed required				9248	14526	21979	32193	45901	
Feed conversion	1.44	conversion rate							
Novel feed as a % of ration	10%								
Total potential Novacq		t		925	1453	2198	3219	4590	
Partner market share				50%	55%	60%	65%	65%	
Potential Novacq				462	726	1099	1610	2295	
Forecast Novacq sales				92	403	822	1378	2110	
Feed cost	$3,000	$/t		$277,427	$1,207,974	$2,464,536	$4,135,400	$6,330,359	
Adoption rate	30%	per annum		$ 83,228	$445,620	$1,184,981	$2,425,601	$4,324,709	
PV	4%		$27,964,073	$76,949	$ 396,155	$1,012,927	$1,993,667	$3,417,880	$21,066,495
PV	7%		$20,858,334	$ 67,210	$323,380	$772,757	$1,421,457	$2,277,478	$15,996,052
PV	10%		$10,893,813	$55,546	$ 242,960	$ 527,803	$ 882,613	$1,285,577	$7,899,314
CSIRO Australian royalties	4%	of feed revenue ex works	$834,333	$2,688	$12,935	$30,910	$56,858	$91,099	$639,842
	5%	of feed revenue ex works	**$1,042,917**	$ 3,361	$16,169	$38,638	$71,073	$113,874	$799,802
	6%	of feed revenue ex works	$1,251,500	$4,033	$19,403	$46,365	$85,287	$ 136,649	$959,763

Year				2012	2013	2014	2015	2016	2017-2026
Wild catch fish equivalent	3	conver sion rate		2774	4358	6594	9658	13770	
Wild catch no longer caught	t			832	2140	4118	7015	11146	
Increase in growth rate	50%			963	1513	2289	3353	4781	
Increased value of farmed prawns using novel feed less cost of production	$16.50	kg		$9,864,071	$15,494,884	$23,444,032	$34,339,325	$48,961,517	
Net increase in prawn farm gate value									
PV	4%		$105,454,385	$ 9,119,888	$8,769,123	$8,431,849	$8,107,547	$7,795,718	$63,230,259
PV	7%		$83,963,653	$8,615,661	$8,052,020	$7,525,252	$7,032,946	$6,572,847	$46,164,926
PV	10%		$68,206,279	$8,152,125	$7,411,022	$6,737,293	$6,124,812	$5,568,011	$34,213,016
Total PV value	4%		**$133,418,458**						
	7%		**$104,821,987**						
	10%		**$79,100,092**						

Data source: ACIL Tasman

These calculations include the deduction of the prawn cost of production used in the breeding modelling. However, there are likely to be addition scale advantages from the increased in production.

The extent to which the novel bioactive feed ingredient would lead to a reduction of wild catch is not clear at this stage. There are three factors that would influence a reduction in wild catch feed production:

- The extent to which others users, of wild catch feed stocks increase consumption as aquaculture reduces its consumption
- The rate of productivity gains of wild catch feeds; the rate of improvements in feed conversion of wild catch (inclusive of total processing efficiency) will determine the amount of wild catch feed used
- Increases in aquaculture production will lead to an increase in feed demand. If this increased demand is not met by non-wild catch feed sources then there is unlikely to be any reductions in wild catch feed use in total.

Table F12 **Fish meal and oil consumption**

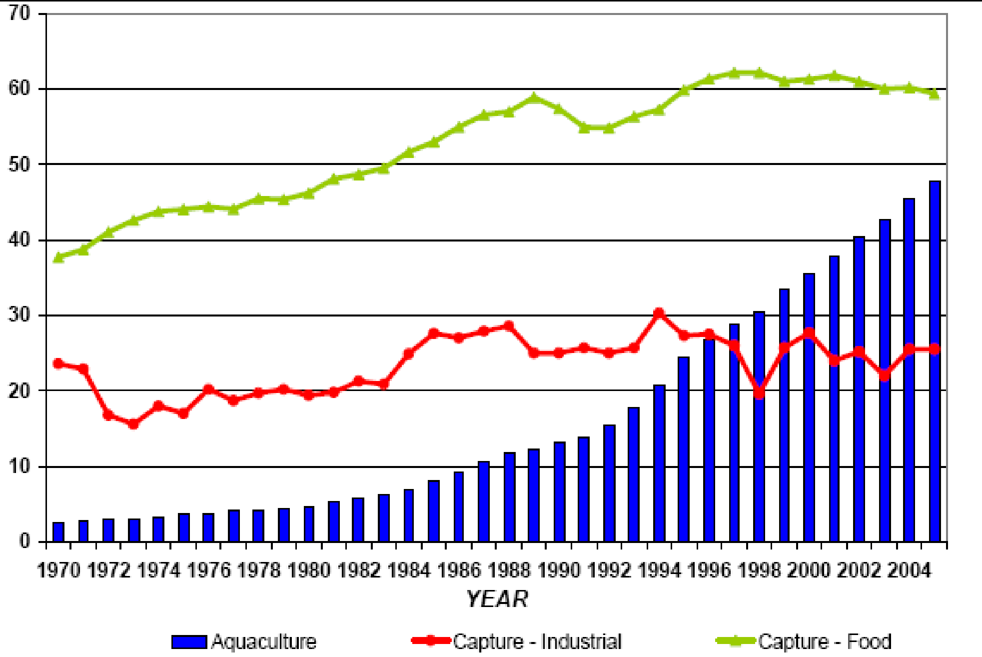
Use	Percentage of total consumption	
	Fish meal	Fish oil
Aquaculture	46%	81%
Pigs	24%	
Poultry	22%	
Other	8%	
Edible		14%
Industrial		5%

Data source: (Shipp, 2010)

The other users of wild catch fish meals and oils are mostly pig and poultry producers. Fish oils are used for human consumption and in industrial processes. The relative consumption of each is contained in Table F12.

In the advent that novel bioactive feed ingredient are used in aquaculture the current level of wild catch could be diverted to other uses.

Chart F1 **World wild catch (food and industrial) and aquaculture production trends (million tonnes)**



Data source: (Shipp, 2010)

The trends shown Chart F1 show the rate of improvement in aquaculture feed conversion efficiency. As aquaculture production has improved wild catch feed (called capture - industrial in the chart) has remained relatively constant.

However, once wild catch feed sources are fully or over exploited, alternative feed sources will have to be found. Therefore the main benefit of novel feed production may be to enable aquaculture to expand beyond the level of production where the availability of wild catch feed stocks become constraining.

> It is considered unlikely that aquaculture will ever consume all of the F&FO resource. If new sources of supply or alternatives are not found, market forces dictate that increasing competition for the available supplies and the resultant increases in cost to feed manufacturers, combined with the need to reduce production costs in fish and shrimp farms, will soon become the determining factors10. The implications of this are serious and obviously mean that for aquaculture production to grow either F&FO supplies will have to increase, F&FO consumption by aquaculture species will have to be reduced and /or alternative sources of essential marine oils and proteins will have to be found. Acceptable and economic alternative means of supplying the nutritional requirements of farmed species must be found or further expansion of intensive aquaculture production (particularly of carnivorous species) will be constrained10. This will be discussed in more detail in the Section on F&FO replacements (Shipp, 2010).

This also posts considerable incentives for others to produce non-wild catch aquaculture feeds or improve conversion rates of wild catch feed. As aquaculture becomes more constrained by wild catch feed sources incentives to develop alternative feeds would grow. At some point alternative feed sources would have been developed. Therefore CSIRO has brought forward the benefits from reducing the reliance on wild catch feeds.

F.9.3 Public benefits

The public benefits of these technologies are potentially large. These can be summarised as:

- Changing the relative costs of wild catch and aquaculture seafood that will alter the incentives to continue to supply seafood from wild caught sources
  - Improving the quality of aquaculture produced prawns to be as good as or better than wild catch seafood to increase the domestic consumption of marine proteins.
- Altering the incentive to continue to fish depleted fisheries and reducing the economic losses of inefficient fishing effort
- The ability to substitute a portion of wild catch feed and increased productivity provide create the option for fisheries managers to explore new policies and/or reduce the costs of existing policy approaches
- Continue to provide animal for protein human consumption should climate change detrimentally affect wild caught fish stocks and terrestrial livestock production

Over fished stocks require more effort to yield less fish. The fish stocks also face greater risks as diminished stocks are more vulnerable to shocks from outbreaks of disease, the effects of climate change and other hazards.

There is a win-win if fishers can be encourage to fish are at reduced levels that allow fish stocks to increase which allows more fish to be caught for the fishing effort deployed. The economic benefit of reducing fishing effort to economically efficient levels is estimated by the World Bank and FAO to be as high as USD50billion per annum.

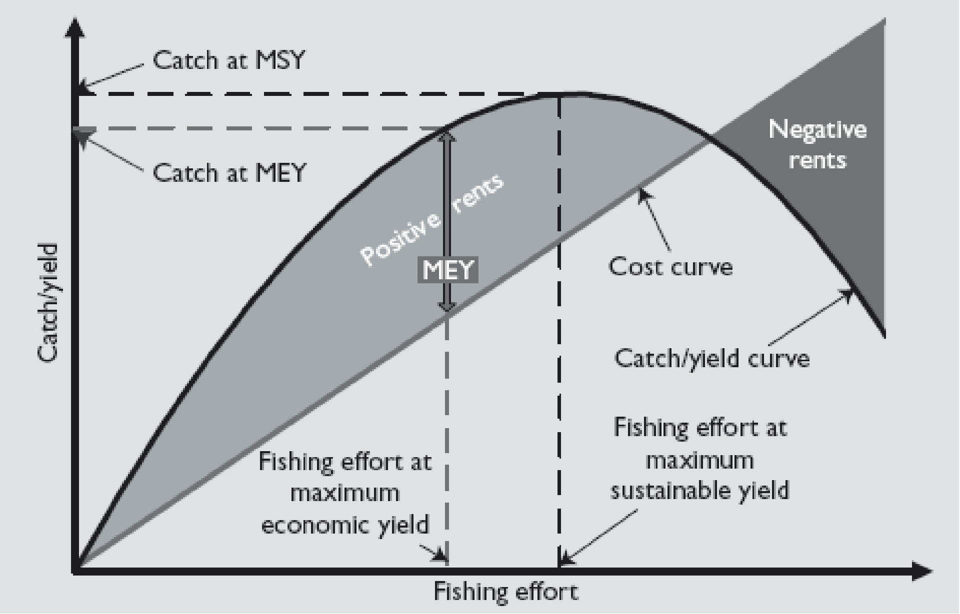
The economic principles of economically efficient fishing effort and fisheries management is shown in Chart F2. Maximum sustainable yield is represented by the apex of the curve. Moving to the right of this point means that fish stocks are likely to decline and are likely to face higher risks of devastation from disease or other shocks.

Fishing effort is represented as increasing linearly with yield. At the maximum economic yield the fishing effort is producing the highest profit, and fish stocks are larger and likely to be more robust.

Therefore shifting the fishing effort to maximum economic yield from maximum sustainable yield increases the profitability of the industry and increases fish stocks— a win-win.

If the price of fish obtained by the fishers reduces, shifting the yield curve down, the incentives to fish decline and fishing effort is reduces.

Chart F2 **Fisheries economics**



s

Data source: (The World Bank, FAO Rome, 2009)

The effect is to reduce the economic losses of fishing at maximum sustainable yield.

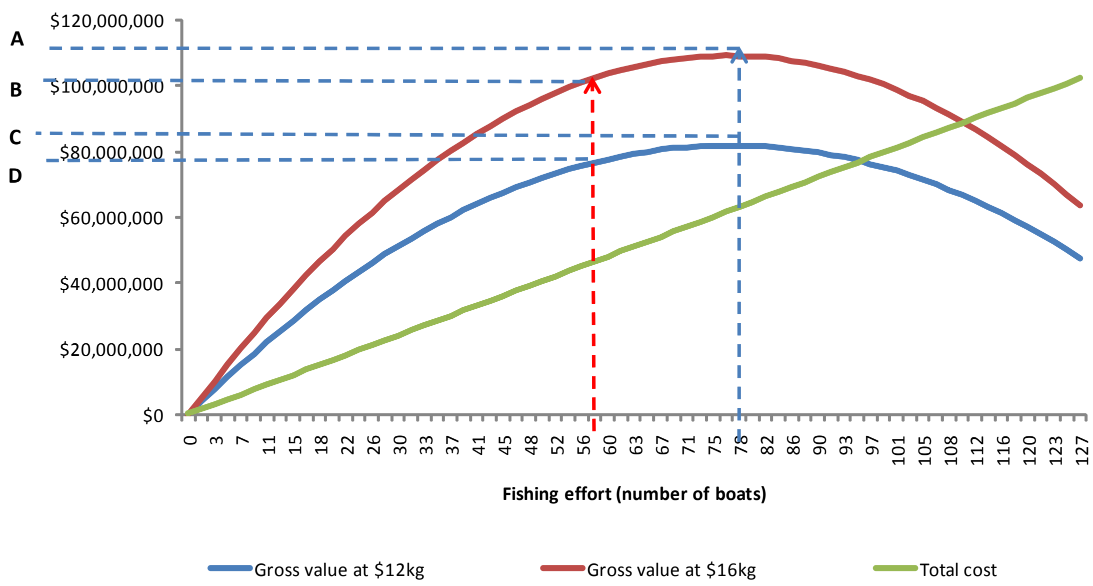
Other estimates of the cost of fishing beyond economically efficient levels are contained in Table F13. They range from US46billion to US90billion. These estimates only deal with the direct fishing effort economic effects and not the social and environmental benefits of increased fish stocks.

Table F13 **Estimated economic losses associate with fishing at maximum sustainable yield compared to fishing at maximum economic yield**

Source	Estimate of losses	Drivers/focus of proposed solutions
FAO 1993	$54 aggregate loss, or approximately 75 percent of the gross revenue	Open access, subsidies
Garcia and Newton 1997	$46 billion deficit	Overcapacity, loss of high-value species
Sanchirico and Wilen 2002	$90 billion (future projection)	Rents in ITQ fisheries approach 60–70 percent of gross revenues.
Wilen 2005	$80 billion	Secure tenure
World Bank (this study)	$51 billion	Comprehensive governance reform

Data source: (The World Bank, FAO Rome, 2009)

Chart F3 **Illustration of price effects on Australian wild catch prawn fishing**



Data source: ACIL Tasman

Using a representation of Australia's prawn fisheries yield and cost curves the effect of a reduction in price on the costs of the fishing effort can be seen in Chart F3. The reduction in the cost of moving from the blue line (maximum sustainable yield) to the red line (maximum economic yield) is shown by the difference in A-B compared to C-D.

The combined effect of the CSIRO breeding and novel feeds technology, if widely adopted is likely to alter the relative price of farmed versus wild catch stock. This is particularly so if the quality of farmed prawns is maintained or increased relative to wild catch and the innovations extend beyond Australia and eventually to other species.

Even if the innovations are adapted by currently domesticated prawn species, the productivity gains will eventually flow through to lower seafood prices, shifting the yield curve down for a range of seafood types.

F.9.4 Other benefits across theme

As referred to in the introduction to this case study the breeding and novel feeds innovations are but one product of a wide research effort to improve both aquatic and terrestrial animal performance to increase the production of protein for human consumption. Some of the other benefits likely to flow from the entire theme investments include:

- World's first development of sensor based devices (collars) that prevent fighting between bulls (bull separation), permit specific mate allocation (precision animal management) and managed herd movement (virtual fencing), which have led to 3 patent[1,2,3] applications and 3 publications[1,2,3]. This project was transferred to the CSIRO Agriculture Sustainability Initiative (ASI) to explore potential of the devices in optimising the use of pasture resources, and the exclusion of stock from environmentally sensitive areas.
- World's first lambs produced using testis stem cell transplantation technology (publication in preparation)
- High speed computing technology (Field Programmable Gate Arrays) was developed for analysing highly repetitive data sets, such as routine genetic evaluations.
- High throughput DNA fingerprinting systems developed and successfully applied to: assess genetic diversity in wild aquaculture founder stocks[4]; tracking changes in diversity in domesticated stocks[5]; pedigree assignment[6]; and generating first-stage linkage maps[7] and gene identification[8] in aquaculture species
- World's first successful production of sterile, all female penaeid prawns[9].

- Immunity and cell proliferation pathways influencing amoebic gill disease (AGD) resistance in Atlantic salmon identified[10] and DNA vaccine against AGD developed. A patent[5] application was filed.

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G Cement substitutes & novel products

G.1 Background – cement and concrete binders

Cement, and especially Ordinary Portland Cement (OPC), has a long history as a key input to building and construction, pipe manufacture etc. Functionally, it has worked well – though with some known issues, such as problems with concrete cancer that need careful management and that have led to some significant legacy problems and costs. Today it is not unreasonably viewed as the second most consumed material on earth – second only to water.

Cement is principally used as the binder in concrete – binding a variety of aggregates to produce a key input to construction. The major market segment that is the focus of CSIRO's work on geopolymers is the market for alternative binders – though wider applications of geopolymers are likely and constitute additional attraction in the research area.

The manufacture of cement, especially the 'clinker' production process, 'sintering', is highly energy intensive – requiring direct kiln burning of fuel (coal, gas etc) as well as drawing significant electricity – while directly emitting CO_2 as a by-product of the chemical conversion. This has meant that cement (and clinker) production contributes about 5% of Australia's overall GHG emissions – and, internationally is a large source of GHG emissions – especially in rapidly developing economies. A consequence of this high energy intensity means that cement production is a very large contributor (over a third) to the emissions from the building and construction sector.

At the same, there is demand for new binders and coatings that can offer new functionality – suggesting possible additional market opportunities for alternative products with some of the attributes offered by cement, but extending into new areas.

The cement industry in Australia and internationally recognises concerns with the sector's emissions intensity and has, since the mid-1990s focused a range of strategies to increase energy efficiency and to substitute various extenders for cement – including flash ash and slag. This has delivered an approximate 25 per cent reduction in emissions intensity

CSIRO is engaged in research and commercialisation that places it at the leading edge of international efforts to develop a range of geopolymer-based substitutes for Portland cement and geopolymer-based products with new functionality.

It is not alone in these efforts – there is a broad base of interest around the world in geopolymer technology. However, commercially competitive major development in this area will require tying together a broad range of threads, from the theoretical end through to engagement in changing standards to accommodate the alternative products. CSIRO is operating across this range, and has serious candidate products, technologies for further tailored product development and product testing and assessment capability that suggests it is strongly placed to play a role in the realization of the opportunities offered by these products.

The team working on geopolymers as cement substitutes has also been working on novel cement products, including a wall panel with lighter weight, reduced emissions intensity and improved thermal properties that has already been commercialised through a spin-off company. This technology offers opportunities for application to geopolymer products and other cement substitutes and so constitutes a part of the value of the options being generated by theme's work, as well as being a direct source of revenues.

This attachment documents the outcomes of probing this theme. It supports a range of value propositions for CSIRO, with direct links into support for industry competitiveness and climate mitigation, and a range of possibilities for also supporting climate adaptation through the delivery of building products better suited to climate extremes.

G.1.1 Environmental impacts of cement

Cement production and use brings with it a range of detrimental environmental impacts:

- It is a dusty and noisy industrial process – approvals for a new cement manufacturing facility can meet with strong resistance;
- Quarrying the input materials can involve dist and noise pollution and aesthetic damage to landscapes.
- Cement manufacture results in significant emissions of carbon dioxide, though the emissions efficiency, in Australia and many other countries, has been increasing significantly over recent years.
  - Current Australian manufacture of cement is about 10 million tonnes annually, with emissions of the order of 6 million tonnes of CO_2.
  - Internationally, almost 3 billion tonnes of cement are produced annually, with CO_2 emissions likely to be well in excess of 2 billion tonnes (http://minerals.usgs.gov/ds/2005/140/cement.pdf).

This carbon intensity incorporates a component due to electricity use, but this is not the dominant source. The bulk of the emissions stem from the decarbonation of limestone and from the combustion of kiln fuel (usually a coal or hydrocarbon product) during clinker production. Limestone, as predominantly calcium carbonate, is the source of calcium to cement production – with cement being predominantly calcium silicates. Limestone binds carbon strongly, and cement production releases the carbon, mainly as CO_2. The manufacturing process occurs at very high temperatures, of the order of 1450°C, achieved through kiln firing, mainly using coal and gas as fuels.

In effect, the process entails three separate processes that each result in the release of geologically stable carbon, locked in rocks or petroleum reservoirs:

- The carbon bound in limestone is released, through the sintering process, as CO_2, accounting for about 0.5 tonnes of CO_2 per tonne of cement.
- The carbon in the coal fuel is burned to release CO_2, accounting for about 0.3 tonnes per tonne of cement (though this can vary substantially up from this figure for less efficient plants).
- Electricity use, if mainly from brown or black coal generation, can account for around 0.1-0.2 tonnes of CO_2 per tonne of cement.

Cement production can make use of a range of other extender input materials to lower the effective level of emissions and to adjust the chemical composition of the final product. Both slag and fly ash are commonly used – and have been made substantially more attractive as inputs by concerns for carbon emissions.

A key corollary of this is that the major emissions from cement production – around 60 per cent – are integrally tied into the chemistry of OPC production. It requires the separation of carbon out of carbon dioxide, and its replacement with silicates. The carbon is strongly bonded, and this requires a lot of energy. Releasing the carbon as carbon dioxide has been easily the most cost effective way of dealing with the waste stream in the absence of any cost penalty on such emissions. If the emissions from cement production are to be reduced substantially, then a fundamental shift in chemistry is needed – or substantially greater uses of extenders will be needed. Both trends are under way and both entail a movement to new binders.

Geopolymers represent a different chemistry, producing a new class of binders, with the potential to reduce these emissions dramatically.

They are not the only way of attacking this problem. Limestone has been formed over time by capturing CO_2.and binding it into a stable rock in combination with calcium. New industrial processes (such as Calera, discussed further in Section G.7 below) are under consideration for again using CO_2 as an input to a geologically stable carbonaceous product suited to use in a range of ways from landfill, through soil conditioner to a cement substitute.

However, geopolymers are widely seen as offering a powerful approach to attacking the emissions from cement production while delivering improved functionality in other ways. As part of the solution, they might well support much more rapid reductions in emissions intensity than would otherwise occur, while offering scope for reducing the detrimental impact of a move to carbon pricing on construction activity.

G.2 What are geopolymers

The term geopolymer is applied to a class of synthetic aluminosilicate materials – reflecting a chemistry that is related to that of cement (though less that of modern Portland cement than of Roman cement). Geopolymers were first named in the 1970s, a French scientist (Joseph Davidovits) who was investigating that class of polymer as a substitute for the organic polymers used in textile production – with the objective of improving fire resistance. However, their relationship to cement had already spawned some interest in the binder characteristics of the class of chemicals starting in the 1950s[41].

The key value drivers underpinning now global interest in research into geopolymers include:

- Their potential for production with much lower GHG emissions than cement – with interest in this area clearly growing rapidly.
- Potential of cement substitution to deliver or support better chemical and thermal resistance and mechanical properties, including durability, in built assets;
  - This includes resistance to pressures likely to intensify under climate trends as discussed in the review of climate adaptation work – including more frequent extreme events, risks of fire and risks of corrosion from greater concentrations of atmospheric carbon.
  - This points to a role in climate adaptation – another key theme across CSIRO and one of the areas considered in our assessment.
- Opportunities for faster curing time, that can have a big impact on overall costs, especially in relation to pre-caste manufacture.
- Geopolymers can be less heavily dependent on large volumes of water than is cement – with this having added interest in lowering risks to water supply reliability and water costs under plausible climate change scenarios.
- Possible other applications as binders in advanced ceramics and composites especially in relation to very high temperature uses.

[41] Indeed one area of interest to Davidovits lay with his thesis that some of the building blocks of the pyramids in Egypt may have been constructed on site, from geopolymers. He further hypothesised that materials used in other ancient structures, including Roman cement, employed geopolymer techniques.

- The potential to draw on a range of waste materials from other industrial processing, delivering waste reduction and limiting pressures on landscape values from further mining of limestone and traditional feedstocks.
  - These waste products significantly include fly ash, mine tailings and bauxite residues. Traditional 'management' of these wastes entails costs in active management, costs in imperfect management (aesthetic, environmental etc) and residual risks that might be mitigated through a commercially viable alternative use such as in geopolymers.
  - That said, cement manufacturers are also increasingly mixing such waste products into their processes as a way of lowering emissions.

The usual approach to production involves reaction of an aluminosilicate powder that can be derived from a range of sources, in clay, flay ash and slag, with an alkaline with an alkaline silicate solution. The process does not require high temperatures and aluminosilicates are widely available. Indeed, silicon-aluminium compounds are a large proportion of the Earth's crust.

In terms of energy intensity and resource availability and accessibility, geopolymers therefore have strong attraction. Nonetheless, setting aside the cost of carbon emissions, the research appears not to be predicated on lower costs of production. Indications are that geopolymers could be produced at comparable cost to cement, with competitiveness dependent on some combination of the direct value of reduced emissions, market demand for greener products in buildings, and the possibilities for better functional properties, including possibly better reliability given various risks.

G.3 What does CSIRO bring to the prospects?

CSIRO's involvement in geopolymer research has emerged out of over 40 years of involvement in building construction engineering, include product design, testing and accreditation. This includes a long history of involvement with cementitious products, including testing and standards, in development of products and standards suited to varying regional conditions and a range of work done on cement systems.

It has already been noted that there is global interest in the development of geopolymers as a substitute for cement. This includes interest from major industrial companies and from cement industry associations.

The Australian Cement Industry Federation (CIF), that includes as members the three Australian producers (Adelaide Brighton Ltd, Blue Circle Southern Cement Ltd and Cement Australia Pty Ltd), already recognises clear commercial drivers for cement manufacturers to pursue strategies to build sustainability and to address prospective carbon costs, regulation and community demands. These three companies have already driven significant improvements in the energy intensity of cement production, have introduced into their product ranges significant use of extenders and are actively investing in achieving further gains.

It is appropriate against this background to ask why there is any need for CSIRO involvement – and especially for Government money – to drive appropriate investment in these possibilities. These are big firms – with some huge firms internationally – seeing risks and aware of the possibilities of geopolymers. Research into geopolymers is under way internationally – mainly directed at developing new products.

The flipside of asking why the need for Government money, is to ask what the chances are that any such money would be wasted? Is CSIRO operating in areas that these international markets have judged are not commercially sound for investment – possibly because of market or regulatory impediments to fast enough take up of the research?

These questions are certainly appropriate. However, there do appear to be reasons why CSIRO may be able to make a difference, especially but not solely in Australia.

The natural strength of these commercial drivers lies at the practical, industrial process end of the sequence of steps needed to deliver a major change. Some universities and other groups are working and collaborating at the chemistry end, where CSIRO also has great strength. CSIRO clearly brings great strength to product testing and standards. Commercial success will require coordination of work across this spectrum – and out to commercial demonstration and market development.

CSIRO brings to this process both additional weight and a legacy of experience that spans the entire spectrum of issues needing to be addressed to deliver a practical solution. In relation to testing and standards, its position and capability is effectively unique. It is this combination that suggests that CSIRO's involvement could materially affect the prospects for early success in moving on this opportunity.

The challenge is not just to develop suitable alternative products, but also to establish that suitability and have it recognised in standards that allow specification of use of a substitute.

Standards in relation to cementitious products have emerged over decades. CSIRO has a long history of capability on product testing and standards development in this area, has the equipment and experience already available, and brings credibility to these processes that would be much harder for a commercial company to achieve. The effect of the implied longer expected delays in agreeing and approving standards is likely to be to fundamentally shift the economics of investment in some of the research in this area – by shifting realistic expectations of rates of market take-up and market premiums.

Standards development is complex, not just because of the diversity of applications of cement substitutes but also because of the diversity of characteristics in the inputs that might be used. Different fly ash products, for example, have quite different characteristics. Different technical specifications are likely to be appropriate in different regions within Australia as well as to different technical uses – with CSIRO's national focus and experience being highly relevant. Standards will need to be capable of dealing with these forms of diversity. This very complexity poses a commercial risk to new product development by commercial firms, unless linked to a standards process that can, reasonably rapidly, assess product suitability and allow for certification for use.

Furthermore, continuing uncertainty as to future carbon policy and pricing adds a further level of risk. The commercial value of these opportunities is strongly tied into the actual price of carbon as seen by commercial suppliers and users of carbon – whether underpinned by an ETS mechanism, a carbon tax or regulation. Governments may see wider value in the development of approaches to reducing atmospheric GHG levels as is discussed in Attachment D. This may well include consideration of the social cost of carbon emissions and the scope for influencing the prospects for a parcel of technologies to emerge that could alter the politics of international agreement on climate change policy. Risks and opportunities might well be seen differently by commercial investors and governments in this situation. We return to these matters in discussing the value and impact of the work below.

CSIRO is the only organisation in Australia, and one of the few in the world, that has activity and programs that span the spectrum from theory, through practical industrial processes and chemistry to regulation, testing and standards – accompanied by close engagement in broader climate policy advice. They offer scope for an integrated attack on the opportunities that would be at best complex to organise otherwise – including in the quest for specific measures designed to limit any adverse consequences from some combination of market and regulatory failure.

These circumstances could well result in a market failure in the incentives for optimal investment in these technologies. Of course, the structure of the suggested failure would strongly support a response that engages both industry and governments – given the remaining interest of industry in developing a solution, if for no other reason than as insurance against possible policy developments, but likely to extend into the prospects for improved functionality. Current cooperative processes through the CRC (discussed in

Section G.4 below, and the active use of commercial vehicles for the products, would seem supportive of this view.

Beyond the ‘in principle’ arguments for government involvement, CSIRO has some actual runs on the board. It already has available to it a range of real innovations, an established relationship with a commercial vehicle for emerging products and an expanding range of new products and technologies.. It has targeted the largest application sector where standards development appears tractable – and it appears to be some years ahead of likely competition.

We return to what these considerations might imply for the counterfactual in Section G.7 below.

G.4 Other relevant Australian innovation

Even within Australia, CSIRO is not alone in its interest in geopolymers. Australian industry has a clear interest. Importantly, there is strong collaboration across research and industry interests and it is important that the value and impact of CSIRO’s role be assessed in terms of what it brings to the prospects for this overall collaboration.

The Centre for Sustainable Resource Processing is a CRC that has a substantial Geopolymers Program. CSIRO is a significant contributor to this program, but the CRC brings expertise from a range of other institutions, as well as industry participants.

The CRC is coordinating, within its Geopolymers from Regional Waste Streams project, the Geopolymer Alliance, whose mission statement has been set as:

> The Geopolymer Alliance aims to bring together research institutes, the engineering fraternity, Government authorities, industrial by-product generators, cement manufacturers, chemicals suppliers, concrete aggregate suppliers, concrete manufacturers, infrastructure owners and industry regulators to co-operatively develop mutually beneficial applications for geopolymer technology.

Furthermore, and of particular relevance, the Alliance has been set up:

> …as a resource centre to provide support to industry and to ensure standards and regulations are available for alkali activated cements and concretes. In addition, the Alliance will conduct workshops and coordinate conferences to assist in promoting geopolymers.

There are currently 15 members of the alliance, covering industry and researchers:

- Industry members include: Alcoa World Alumina, Anglo Platinum, BHP Billiton, BlueScope Steel, GHD, Newmont Australia, OneSteel, Orica, Rio Tinto, Rocla and Xstrata

- Research providers include ANSTO, Central TAFE WA, Curtin University of Technology, CSIRO, Murdoch University, The University of Newcastle and The University of Queensland

The alliance then offers an interesting and potentially powerful platform to improve substantially the prospects of a comprehensive assault on geopolymer opportunities in Australia. It coordinates the various research streams, it provides natural access into potential industry participants in operationalising successful outcomes and it has a primary function of addressing standards and regulation to limit any constraints on appropriate take-up and hence strengthen the value of any options emerging from the research streams. This key emphasis in standards and regulation plays especially strongly to CSIRO's capabilities and interests – though CSIRO's relevant capabilities and contributions to date are substantially broader than this.

Both the CRC and the Geopolymers Alliance are key elements supporting the assessment below of the value of CSIRO's involvement with geopolymers.

This said, CSIRO's work with geopolymers commenced ahead of, and continues in parallel with the CRC activities. Thus not all of the CSIRO work is channelled through the CRC. This is particularly true of its commercial partnerships and negotiations for commercial arrangements in relation to product developments.

G.5 What has CSIRO achieved?

The complex mix of players mapped out above raises natural questions of attribution and assessment of additionality of benefits. The key question is how much more value has been created as a result of CSIRO's involvement. This relates clearly to areas where CSIRO has brought critical mass and/or unique skills, has been able to plug particular gaps in coverage, has been able to offer different lines of attack etc.

Opportunities can be broadly classified as precast products, premix products and specialty coatings. Each has commercial attraction and the boundary between the markets for the first two is not rigid. For example, floors can be constructed using precast panels as well as on-site pouring of a premix product. However, the current stage of product development has allowed earlier development of the precast products sector, while pursuing opportunities in the other sectors that may well offer much greater long-term value.

G.5.1 Precast products and HYSSIL

CSIRO-developed geopolymer IP has already entered the commercial market via its relationship with the Australian company HySSIL. CSIRO established

HySSIL as a start-up company explicitly to develop a subset of the opportunities for cement products and substitutes stemming from CSIRO-created IP. CSIRO's position remains an equity one. It stands to benefit directly from the profits of HySSIL translating into increased share price, rather than from royalty payments by HySSIL. At the same time, HySSIL's business model favours the establishment of commercial agreements to license technology with local and overseas firms for specific products, where its revenues would then come principally from royalty payments.

Given CSIRO's function to support Australian industry and the fact that it remains a major shareholder in HySSIL, we have not sought to dissect too finely the distinction between the two in assessing impact and value to Australia. Royalty benefits will be shared and will accrue to Australia.

HySSIL has already commercialised one CSIRO technology – to produce a lightweight foamed concrete panel product with some attractive features:

- 40 to 50 per cent lighter than conventional concrete panels of similar strength;
- Three to five times the insulative properties of equivalent concrete panels;
- Very high fire resistance;
- Lower embedded GHGs as a result of the reduced use of cement;
- Cost competitive ex factory, but with scope for greater competitiveness after cost savings from lower weight and better thermal properties are fully factored into facility design.
- Supporting primary applications in:
  - Structural and non-structural building walling systems;
  - Cladding systems;
  - Fences;
  - Acoustic panels; and
  - Party walls.

CSIRO is now working with HySSIL on two specific geopolymer products where the standards issues have been relatively easily addressed and that offer good opportunities to demonstrate the commercial application of geopolymers as concrete substitutes:

- A pre-cast panel product.
- A lightweight roofing tile for which a particular opportunity is being pursued in the US, where traditional tiles are substantially lighter than conventional Australian concrete tiles and where *replacement* tiles need to have similar light weight.

   - Many roofs have been engineered for a lighter weight tile that is become harder to obtain, but as a result the rooves are not well suited to retrofitting heavier tiles.
   - Current sales (extracting from current depressed activity in the construction sector) of lightweight tiles in the US amount to about 8.5 million squares annually, with a value of about AUD1 billion.
     … This compares to total US tile sales of 138 million squares[42] with a value of about AUD15 billion.
   - Product development is being undertaken between HySSIL and a major US roof tile company, with the product now undergoing trials in the US. The partner currently supplies about 10 per cent of the lightweight tile market in the US and is a major player in the broader roof tile market.
- HySSIL is actively pursuing opportunities to move these capabilities into new product niches and new markets.
   - It is in the nature of the processes being used that they should be competitive into an expanding range of markets and product opportunities over time – particularly in explicit carbon pricing is more widely established.

These specific developments are being pursued via commercial agreements that will allow CSIRO to derive value, via capital appreciation of its shares in HySSIL, from successful licensing agreements that translate to sales. The potential in these relative niche applications is significant – and reasonably accessible given the pre-cast product characteristics.

An example of another potentially significant if still niche opportunity comes from the market for railway sleepers and, especially, for replacement sleepers on existing track where timber sleepers are currently installed. Traditionally, timber was used, with heavy use of concrete sleepers now being common in new rail build. Factoring in the greater frequency of replacement, timber sleepers have over 6 times the embodied GHG emissions of concrete sleepers[43] – pointing to the even greater potential for emission reduction if a geopolymer sleeper could substitute for concrete or timber.

However, there is also a substantial demand for replacement sleepers as part of normal track maintenance. An issue with concrete sleepers is that the lack the elasticity of the timber sleepers and need therefore, in many cases, to be thicker than the sleepers they are replacing. This can add substantially to the cost of

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42 A square is 100 square feet, or about 10 square metres.

43 Crawford, R.H. (2009), Greenhouse Gas Emissions Embodied in Reinforced Concrete and Timber railway Sleepers. Environ. Sci. Technol. 2009 43 3855-3899. Viewed at: http://pubs.acs.org/stoken/presspac/presspac/full/10.1021/es8023836?cookieSet=1

track maintenance, and tends to favour use of timber sleepers even though the cost of these is rising.

Geopolymer sleepers appear suited to the manufacture of a replacement sleeper with the same thickness as timber sleepers. This could represent a substantial opportunity, which appears well-suited to exploitation. It can certainly be seen as part of the set of options already created by CSIRO – and where a credible path to market is already in place. Indeed, CSIRO has undertaken work to design a geopolymer-based alternative product, exploiting the functionality of geopolymers to deliver a sleeper with the same thickness as the timber products it might replace. It has also entered into discussions with potential commercial developers of the product.

Crawford cites figures of 7 million railway sleepers in Victoria, with 29 per cent being timber sleepers needing replacement. This would suggest something in the vicinity of 8 million timber sleepers coming up for replacement nationally – and many times more internationally.

An attractive feature of these pre-cast product opportunities is the indications that products can be competitive, or more than competitive, with the concrete products they might substitute for, even before taking into account any aspects of the carbon emissions. This appears true of the geopolymer panels, as noted above, and is expected to support strong demand for roof tiles after factoring in the load-bearing characteristics of the US roofs where these tiles could be used to replace existing low weight tiles. Effectively, these products exploit both comparable production costs and functional characteristics that make their use lower cost – avoiding costs in reengineering the structures to which they are to be applied.

Similarly, the economics of the sleeper prospect is heavily tied into the scope it offers to replace timber sleepers without the need to reengineer the bed into which the replacement sleepers would be inserted. This is a market where concrete is already preferred to timber in new track for reasons of longevity, but where retrofitting concrete involves substantially higher installation costs. This suggests that a geopolymer sleeper with broadly comparable costs of production to concrete, with either or both of lighter weight and greater compactness for transport and with the thickness of timber could be highly competitive. The lower embedded emissions intensity would, of course, add to this competitiveness were the emissions to be priced or regulated.

Of course, there is nothing in the reasoning to suggest the same sleepers could not compete into the new rail track market – it is simply that the rising cost of timber sleepers creates a more immediate incentive on the demand side to consider a geopolymer product. Longer term, if the above features could be met with a geopolymer sleeper, it looks likely to be competitive with concrete, especially if the embedded emissions are priced or regulated. Were it able to tap a substantial market in replacement, then this might underwrite the risks in moving to a scale sufficient to allow it to compete effectively into the total market for sleepers.

The ability of these products to compete and rates of take-up would, of course, be substantially assisted by the emergence of explicit carbon pricing or supportive regulation, in Australia and or in target markets or other countries supplying concrete products into these markets. Such developments could, in fact, open up new market opportunities where geopolymers might not otherwise be competitive.

The heightened water intensity of geopolymer manufacturer would need to be considered in making these assessments – especially if the climate trends and concerns driving carbon pricing are likely also to push up the effective cost of water. However, the potential for increasing competitiveness in a carbon constrained world would seem substantial.

G.5.2 Premix products

These opportunities in pre-cast products are, collectively, quite large in potential value – and could underpin significant royalty streams back to CSIRO. However the biggest opportunities, especially if consideration is being given to reductions in GHG emissions, will require successfully addressing the standards issues in relation to specific geopolymer chemistry (dependent in raw material sourcing etc) and ultimately moving to compete into the very large volume markets for concrete in construction – including on-site pouring of foundations, slabs and slabs for buildings, and on-site pouring of road bases, bridge structures etc. This is different from (though clearly complementary with) the product possibilities being pursued via HYSSIL.

When approached in this way, there is potential value both through product sales that delivery royalties (and, in turn, capital appreciation of equity investments or dividends from those investments), and in the impact of the work on enabling earlier substantial reductions in the GHG intensity of concrete and possibly in contributing to influencing the prospects for a better outcome in international negotiations for climate mitigation. We would not see CSIRO's impact as being to effect a huge change in the prospects here, but the scale of the opportunity is large enough that a small change in prospects could have high value.

Again, CSIRO brings a background and credibility in concrete product testing, combined with its expertise in relation to geopolymer chemistry, that does imply an almost unique capacity to make reasonably rapid progress with the simultaneous development of products and standards. This work is being sensibly coordinated through the CRC – and is greatly strengthened by the complementary research and industry capabilities and funding that this offers, but it does seem that the prospects for early progress with these very large opportunities for substitution of geopolymers for cement would be greatly weakened without CSIRO strong presence in these processes.

The CRC is reaching the end of its 7-year funding cycle. We understand that the participants are preparing a rebid, under CRC Round 13, for a further 7 years for a repositioned CRC, tentatively called the CRC for By-product Utilisation (CBU), with significant proposed industry investment in the geopolymers area.

It is our understanding that CBU, if it proceeds, would make a strong shift in the geopolymer emphasis onto these standards and regulatory issues[44], where CSIRO offers special, arguably quite unique, strengths in capability and credibility. Additional areas where CSIRO capability would bring particular strength and value are:

- Generation of long-term durability data and development of appropriate test methods; and
- Conducting of demonstration projects with selected industry partners, such as the processes now in train with between CSIRO and both active and prospective partners.

We are not in a position to judge the CRC bid, but we observe that the concept, in relation to geopolymer opportunities, appears to involve a systematic assault on a market/regulation failure risk that could otherwise substantially impede the generation of real value. CSIRO capability would seem crucial to the proposed strategy – indeed, substantially more so than has been the case with the present CRC.

We stress again that standards and testing for concrete substitutes is made complex by the large variation compositions of products that can be achieved through geopolymer technology. It is not a standard product. The ideal source of concrete for one application in one region may be to make heavy use of a local input that will affect product characteristics to an extent that is not true of Portland cement specifications.

CSIRO links product chemistry, testing facilities and long-term engagement in product testing and standards. It has been promoting an approach that focuses first on opportunities where the standards issue are more tractable –

[44] The CBU proposal argues for a strategy to "accelerate Standards development of Geopolymer technology and thereby capitalise on a significant opportunity for Australian businesses to lead the world in establishing industries based on these new materials."

and getting products into these markets – while progressing with the more difficult, but potentially higher value, opportunities.

We attempt, in Sections G.7 and G.9 to draw some conclusions about the significance of this capacity being available.

G.5.3 Coatings

A third market segment involves possible application of geopolymers. A key component in most coatings is again a binder – a geopolymers are binders. However, a characteristic of geopolymers is that they (like cement) are brittle and for thin applications this is a problem. A range of organics can be used as binders in coatings, but these come up against a temperature limitation – they become unstable at higher temperatures that can be relevant to many applications – such as brake parts,

CSIRO has developed and patented a hybrid technology that combines the pliability and adhesive properties of epoxy binders with the high temperature stability, strength and acid resistance of geopolymers.

This offers a totally different range of market opportunities for a different class or product – but one reliant on essentially the same chemistry. The characteristics of the hybrid suggest strong potential for applications such as machinery parts. Potential markets here are very large – covering automotive brakes and clutches and a wide range of industrial friction materials.

The coatings could also be designed for application to fabrics, opening up opportunities such as safety clothing where resistance to high temperatures and to sparking could have high value.

G.5.4 Other market possibilities

Similarly, there are probable applications in relation to high-impact polystyrene, commonly used in toys and product casings, and where there is considerable commercial interest in higher temperature tolerances, with low levels of toxic fumes.

Highly specialised, potential very high value, markets are being explored with commercial partners – including applications to a range of industrial facilities where the potential for very rapid construction relative to concrete and other products offers considerable value if it can be realised.

Another area being explored is application to shipping panels.

Given the variability in input sources, and the number of levers available for manipulating the geopolymer structure to meet functional requirements, there appear to be significant opportunities in the development of algorithms and software that would allow real time adaptation of production processes to accommodate changing input characteristics. CSIRO could be well placed to bring to these opportunities great strength based on a range of areas of existing capability.

The aggregate value of these markets is of course huge. The particular niche within which geopolymer-based products might be competitive in the short term is likely to be a lot smaller, but may still represent a large collective opportunity for this technology.

G.6 What pre-existing capabilities have been used?

The work on geopolymers has drawn on capability from across CSIRO as well as through the wider network, including the CRC. The research program currently resides in the Future manufacturing Flagship, within the Cleantech manufacturing theme of work. Specific areas of CSIRO capability that have made important contributions include:

- Material science/engineering capabilities around silicate systems chemistry/synthesis, materials blending/formulation and design of high strength binder systems
- Process science/engineering capabilities including mixing, rheological control and thermal conditioning/curing
- Materials performance assessment – including durability,
- Fire science/engineering
- Life cycle analysis
- Structural mechanics/engineering

Successful development of major opportunities, with product, documentable product characteristics, standards in place and an ability to demonstrate compliance with standards and effective market chains is a complex requirement that would not have been possible, in the timelines of the Flagship and this program, without access to these capabilities, and the ability to focus the capabilities on the program task.

G.7 The counterfactual

Clearly, geopolymers are going to develop in product range and actual use over coming years – they offer a combination of attractive features and are the subject of serious international research efforts. Without CSIRO's involvement this would happen over time.

Within Australia, a range of companies is already active in exploring possibilities outside of the CRC processes – including Boral, CSR and James Hardie. Zeobond is another Australian company with similarity to HySSIL. It is linked into technology and research through Melbourne University and is currently both demonstrating technology and producing a select range of precast and premix products.

However, CSIRO has already established an impressive platform for pursuing niche product opportunities that suggest it is significantly ahead of competition in at least these niches – this includes some potentially substantial overseas markets. Furthermore, the range of new product opportunities is vast, suggesting a lot of scope for creating valuable niches, even in the presence of comparable capabilities in other forms or alliances. There seems no question but that the geopolymer space will in the future be characterised by multiple companies operating in overlapping areas. There does appear to be an opportunity for Australia to be an early, successful mover in this space, in relation to supplying products domestically and moving into overseas niches.

The standards issues, at least for substitutes for the very large volume uses of concrete, are likely to be strongly linked to cost effective raw material inputs and to regions and applications. This strongly suggests that CSIRO's capabilities could be instrumental in making a substantial difference to the development of these product opportunities at least in Australia – given the unique capabilities that CSIRO offers, stemming from many years of active engagement in research into construction systems. Zeobond could well benefit significantly from CSIRO success in encouraging a more rapid development of Standards.

The extent to which the economics of geopolymers will rely on costs being attached to the carbon emissions from cement production is an important consideration. A breakdown in efforts to post a carbon price and/or the development of a cost competitive carbon capture and storage process could limit the success of geopolymers or, more probably, slow the rate of take-up and limit the areas in which it proves competitive.

Cement production, like electricity production, could support delivery of a CO_2-rich gas stream into a post-combustion capture and geological sequestration process. However, present indications are that this looks very expensive and the current indications of the costs of geopolymer replacement suggest that this technology would not be competitive for cement. More radical options for carbon capture could change this equation. One example is the Calera process for converting the CO_2 and saline brine inputs into stable, solid minerals and less salty water – possibly supporting as a by-product cheaper desalination etc[45].

[45] We note that the Calera website (www.calera.com) suggests cost effective application to cement production as well as power generation and flags its potential for application as a

Trying to map out the counterfactual as a scripted path of development of geopolymer-base concrete substitutes is both difficult and likely to be lacking in credibility. We incline to the view that there will be progressive take-up and that it will not occur overnight. The key question in probing CSIRO impact and value is to ask to what extent CSIRO's involvement has altered the nature of these development possibilities – in terms of the rate of product development, the rate of market take-up etc.

This is the approach we adopt in Section G.9 below.

G.8 Theme resourcing and costs

CSIRO has committed around 42 EFTs to geopolymer research over the past 10 years, with current resourcing of about 7 EFTs. Total salary costs across the period would be of the order of $7-8 million, with total costs of the order of $15-20 million.

Weighed relative to the potential seen for geopolymers, and the opportunities for Australia, this investment might be viewed as modest – provided that it has added significantly to the prospects in this area, which appears highly plausible. On the other side, the markets remain small, and even the commercial firms operating in the area are focusing as much on demonstrating capability as on meeting demand. There are tangible products, highly attractive possibilities – but not yet huge levels of return on this investment, let alone the total investment across institutions and firms.

These comments are not meant to be pessimistic – they are entirely consistent with the emergence of a fundamentally new approach to a wide range of market prospects. They do, however, flag risks for investment as well as representing large opportunities.

G.9 Value indicators

Trying to script the development of the huge range of market opportunities for geopolymers, and to attribute back to CSIRO a proportion of this value, would necessarily be highly speculative.

In terms of market development, it seems highly probable that a large portion of the market for OPC will be replaced by a lower emission product in the medium term. Indications are that geopolymers could do so at little, if any, cost disadvantage ignoring the cost of emissions, and at a distinct advantage if

retrofit across several industrial processes. Other approaches to mineral carbonation are in development, including one recently announced by the University of Newcastle – supported by the NSW Clean Coal Council. The University is a participant in the CRC.

emissions are priced or regulated. Large scale progress with the technology will, however, require that the standards issues and the practical systems for relating the technology to available raw material input sources are resolved – and there is every reason to expect this to happen in time.

There is also a very strong basis for inferring that the active role of CSIRO – covering key aspects of standards and testing, and specific aspects of the technology development, demonstration and commercialisation – could have a very significant impact on timing and extent of such substitution.

Major value propositions can be viewed in several groups:

- Opportunities for CSIRO to derive a commercial return on its investment of time and resources and its risk taking on this area of work.
  - A natural vehicle here would be the successful growth of HySSIL, including revenues it derives from product sales and from licensing of IP into a growing range of niche markets – including the roof tile and concrete panels markets, where early returns are now reasonably assured, but extending into other niches over time.
  - CSIRO is also in discussions for a range of other commercial relationships including in relation to its sleeper product.
    - … Analogous opportunities exist in relation to overseas markets, noting that CSIRO controls patented IP.
  - As standards and testing procedures emerge, the range of opportunities grows substantially – especially if CSIRO continues to control access to key IP in terms of translation into commercial products in the large volume markets such as construction slabs, roads and bridges.
  - A further, potentially large opportunity, exists if CSIRO is successfully in developing systems for continuous production based on real time adaptation to changing input characteristics.
  - The major commercial opportunities here are probably more closely related to the early mover advantages of early access to suitable, standards-compliant capabilities rather than expectations of capturing the whole market indefinitely.
    - … The range of players is large, the scope for engineering alternative geopolymers to comply with emerging standards is very considerable and emergence of strengthening carbon prices would provide growing incentives for such competition to arise.
    - … Ultimately, competition across this product range is likely to be desirable in maximising the rate at which new functionality emerges and the rate at which the substantial emissions attributable to conventional cement production are clawed back.
- Contributions to competitiveness and growth of Australian industries.

- The commercial partnerships that are emerging, and that are under consideration, clearly point to interest within industry in engaging early in what is seen as a future growth sector.
- The commercial linkage that has been established between HySSIL and the large American roof tile firm points to the scope for these commercial opportunities extending at least into international niches.
- Existing cement manufacturers have an established strong interest in the development of substitute technologies as both opportunities and insurance against future emissions pricing or regulation.

• Contribution to altering and improving the emissions abatement curve faced by Australia in developing its emissions policies – and therefore to lowering the costs to Australia of complying with any targets or other arrangements to contain emissions.
  - With concrete products accounting for about 5 per cent of Australian emissions, the potential for new technologies, such as geopolymers, with comparable production costs and much lower emissions to make a substantial difference to these costs would seem to be high.

• Increased potential for a consequential raising of the politically acceptable level of commitment to lowering Australia's emissions.
  - There is of course a trade-off between the cost savings in meeting a specified target and the potential benefits from therefore agreeing to higher targets, but there is likely to be value in the expanded range of options Australia has for addressing climate mitigation in terms of its own emissions.

• Potential for exports of products or technologies to other countries to further contribute to either or both of reducing the costs of achieving given levels of international reductions in emissions, or to make additional reductions politically feasible.
  - The applicability of these technologies to countries such as China and India, where massive use of cement or substitute binders in concrete can be anticipated for many years into the future, points to some interesting possibilities.
    … These technologies – in concert with successful development of other technologies such as cost effective carbon capture and storage (where Australia is also heavily committed to an international effort) just might be capable of allowing a significant shift in the international politics of climate mitigation.
    … Effectively this could follow from a package of large scale technology changes that, collectively, would lower the costs of these rapidly developing economies committing to deliver of significant restraint over emissions.
  - The reasoning above points to a probably modest chance of this technology being part of game changing mix of technological

developments that allows for a different approach to be taken to climate mitigation.

… We would be loath to suggest that CSIRO's role in accelerating the early moves into this technology would have a large impact on these prospects, but the potential size of the 'prize' may be large enough that a very small influence over a low probability outcome could still have very large value.

… This value would lie in the impact this work could have on the portfolio of strategies to make emissions restraint more acceptable internationally – with this value being unlikely to be a simple stand-alone, additive component of value. Rather it is likely to alter the chances of global processes crossing a threshold as a result of a series of cost competitive mitigation prospects coming together. As such, it could be seen as creating useful extra insurance against failure, or underachievement, in global climate mitigation efforts.

… Effectively, we are suggesting that this area of technology and its overseas application, and CSIRO's role in advancing its prospects, can be viewed as an 'extra iron in the fire' within the sense used in our 2006 report, shifting the statistical character of the forward distribution of possible mitigation strategies in a way that could create value for the globe and for Australia.

We have not attempted to quantify all these value components – though wider review of the value of carbon abatement is discussed in Attachment D. However, we have explored a number of indicators that collectively suggest the downside risks with this investment by CSIRO are now looking very modest, and that the upside is very considerable across several of the above value factors. We have left unquantified a range of options that appear likely to have substantial collective value.

G.9.1 Commercial returns – current products

The US replacement tile market is a niche with opportunity for very early application. Commercial agreements are in place and a product is being moved to the market. We see it much as an earlier demonstration of the potential for these niche products – especially where competitiveness comes from significantly better function – as it is a source of revenue in its own right.

That said, some indicative numbers are possible against the following background (including the figures cited in Section G.5.1):

- The US partner currently commands about 6.2% of the US roof tile market.
- The commercial arrangements are in place, with a market ready product with functional characteristics that satisfy a significant niche, and with potential for application across a much larger tile market.

- The most pessimistic assumption is that there is effectively no market development, and no royalties are paid.
  - Given the stage of development of product and its functional characteristics, this does seem pessimistic, but we have assumed a 50 per cent risk of this happening – probably conservative.
- A 'minimalist' scenario involves the US partner only cannibalising its own tile market, but moving over 5 years to replace 10 per cent of its sales with the alternative product – with demand being driven by the savings in installation costs. Sales would then hold at year 5 levels, with no penetration of the wider market.
  - We have attached a 35 per cent chance to this occurring.
- A more optimistic assumption mirrors the pattern over the first 6 years, but allows, from year 7 onwards, progressive penetration of the wider market in lightweight tiles, such that by year 10 the partner (or the partner alongside additional commercial arrangements) accounts for 25 per cent of the lightweight tile market).
- We assume the tiles sell for the same price as current concrete tiles and that a royalty of 2% per cent is paid on sales.

This should be seen only as a stylized representation of what is in fact a spectrum of possibilities, theoretically ranging much higher in potential, as well as filling in space between these 3 scenarios.

It is also important to recognise that any of these possibilities, but especially the minimalist and opportunistic scenarios, could be expected to deliver additional option value. A successful partnership with a major precast concrete products company, where that company recognises the value in moving its geopolymer capability into new areas, could have substantial value.

This of course includes penetration of the broader tile market. The 'niche' has been assumed to be only 10 per cent of the total market and at the most optimistic end the company is assumed to have tapped only 25 per cent of this – 2.5 per cent of the total market. If carbon pricing were to come in, or regulatory measures were adopted (such as housing energy ratings etc) to encourage use of products with lower embedded energy, then the upside opportunity could be a lot larger.

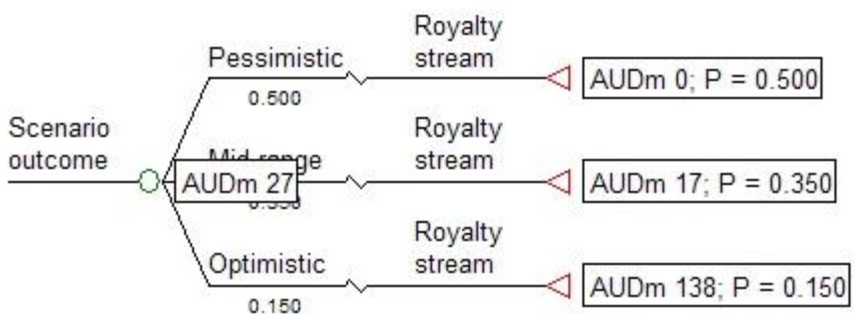
Having noted that, this stylized and probably highly conservative model of commercial returns can be represented as follows:

Figure G1 **Structure of stylized roof tile possibilities**

Source: ACIL Tasman modelling

Based on the modelling done, these possibilities can be solved in terms of outcomes for each of the 3 scenarios, plus a risk-weighted value of the royalty streams. Using a real discount rate of 7 per cent and an assumed AUD/US exchange rate that averages 0.80 implies the following solution:

Figure G2 **Roofing tile scenario outcomes**



Source: if ACIL Tasman data

The assumptions imply an expected value of the revenue stream of $27m, with a potential upside value of $138m, before accounting for the value of additional upside options.

Of course, this figure is heavily driven by the optimistic scenario. Dropping the probability of this emerging down to 5 per cent lowers the expected value to about $15m. That said, the characteristics of the product do suggest a real chance of competing for a slice of the 94 per cent of the tile replacement market not currently supplied by the partner – as well, of course, as the prospects for expanding beyond the specialist replacement tile market into the general market. Such a development would probably open up fresh value prospects in the tile market in Australia and elsewhere, especially if carbon pricing or strengthen regulation was introduced.

Against this background, and given the stage of commercial development we would see the above assessment as conservative.

Of course, there are ongoing costs for HySSIL – and there will be additional costs for CSIRO in tapping the wider options. This will include investment in on-going technology development, to sustain a competitive capability. This market is not seen as being likely to cover the total investments costs already incurred and in prospect. Instead, it is an advanced indicator of a form of value that could be found in a range of applications of geopolymers to niches – spreading the 'overhead costs' already incurred.

We have not formally modelled these other prospects – their logic will be broadly similar, though clearly a larger set of up-front costs will be needed in some cases to secure the options. The railway sleeper replacement appears to have scope for being highly competitive into a market of the order of 10 million sleepers in Australia in the near term – and many more overseas. The panels market may take longer to emerge, but is potentially much larger.

It is against this background that the prospects for the geopolymer panel technology that HySSIL is now marketing, the serious prospect for a more cost effective and lower carbon replacement railway sleeper (with market opportunities again into the US and many other countries, as well as Australia) needs to be weighed. The prospects for values of this order or greater compounding over several years appear substantial – and again would be driven harder by stronger emissions policy. This could include success in accreditation of geopolymer panels as part of the 6 and pending 7 star energy and emissions rating of buildings – where the work being undertaken in CSIROs Sustainable Ecosystems Group appears quite relevant.

Across the set of essentially existing products the prospects of revenues in the several tens to hundreds of millions of dollars over the next 10 to 20 years does seem quite plausible – while at the same time strengthening the base for the wider application of the technologies and opening new revenue streams.

G.9.2 Commercial returns – new products

Major new opportunities do exist in the pre-mix market and in technologies, such as real time mixing systems.

To give some feel for the size of the opportunity we note the following:

- CSIRO already has products that current testing strongly suggests can comply with likely standards in relation to concrete slabs etc – and is well placed to develop an evolving product range and capability.

  - The technology is proven
  - Latent demand is high
  - External trends favour growing demand
  - CSIRO is active and well placed to address the major impediments to early progress in relation to standards and testing.
- There is competition from other firms engaged with geopolymers, from the trend to increasing use of other inputs to cement production and from possible new products, such as Calera.
  - That said, we note that HySSIL's aerated concrete product could utilise an alternative binder, including one from a Calera-like process, and add significant value through expanded and greater product functionality, while delivering substantial reductions in emissions from these aerated products.
- Australian production or pre-mix concrete in the 12 months to March 2010 was just over 20 million cubic meters, which aligns with about 10 million tonnes of cementitious product manufactured in Australia.
  - Price varies very substantially over form, location and use, but with an indicator value of $200 per cubic meter, this translates to an annual market of the order of $4 billion.
  - Very modest penetration of such a market, at a low royalty rate, could still amount to very substantial revenues.
    - … For example, access to each 1 per cent of this market at a royalty rate of 1 per cent would be worth almost $500K in royalties. The value of the commercial opportunity may be substantially greater.
    - … The objective of the emissions-driven investment in a geopolymer substitute for cement is to compete for a much larger share of the market than this – with expectations that this will be driven further by emissions pricing and regulation.
    - … Cement substitutes already account for approximately 25 per cent of the market – up by about 150 per cent over the past 20 years, but with key extenders, such as slag, now in limited supply (and being imported).
- Strictly as an indicator value, linear growth over 20 years to 25 per cent of the current pre-mix market (substantially less of the likely future market) would, on this basis, imply a royalty stream with a present value of the order of $40 million, and an annual royalty of the order of $10m per annum at the end of the 20 years.
  - Maintenance of revenues across this time period would be reliant on progressive improvement of product characteristics or processing systems – including possibilities for continuous time processing.
- Shifting the technology into overseas markets such as the US, even with only a tenth of this market penetration, could be worth much more.

It is probably not sensible to try to focus on a single indicator value for these prospective markets, but certainly the size of the potential opportunity, the likely strength of the drivers for take-up and the prospects for CSIRO helping to shape earlier change in standards do suggest value of the order of at least tens of millions of dollars, with significant upside.

G.9.3 Who would capture the commercial returns?

The above calculations have been based on assumed low but commercially common rates of royalty for access to IP. Significant benefits are likely to fall also to the industry partners who choose to enter into such agreements.

CSIRO's brief extends to support for Australian industry and these wider benefits would fit such a concept. Successful development of these products might offer valuable insurance to the players in the existing cement industry – who have a keen interest in moving to less emissions intensive products – and to other firms, including SMEs and start-up firms, who may move into specific niches.

We are not well placed to judge how the benefits would be shared between CSIRO and industry – with indicator values being derived on the basis of common royalty rates. It would be possible, with movement of emissions pricing, that CDSIRO could be in a position to obtain a substantially higher share of the commercial value at least in the shorter term. This might cut across other values, such as emissions reduction, by slowing the rate of take-up.

G.9.4 Comments on the value of carbon abatement

The main driver of, and key attraction in. geopolymers as a technology is there potential to deliver significant abatement of the CO2 emissions currently associated with cement production. Art both the Australian and global levels, the values here are potentially large, while the cost and functionality features of geopolymer products mat mean that that this abatement can be achieved at low cost.

Purely as indicator figures, we note that:

- 5 per cent additional market penetration, starting in 2020, than would otherwise occur, and lasting for 5 years, would entail emissions with a value in excess of $50 million assuming an ETS is in place – and a similar social cost of carbon emissions if not.
- Similar rates of substitution globally would involve savings associated with the social cost of carbon of tens of billions – with associated incentives and capacity for more aggressive global abatement.

H APSIM

Key points

- The Agricultural Production System sIMulator (APSIM) is the leading example of CSIRO's extensive agricultural production systems modelling. This modelling involves computer simulation of the complex bio-physical interactions characteristic of agricultural and forestry land use systems
- APSIM, and agricultural and forestry production system modelling and decision support systems (DSS), have a long history within CSIRO and constitute an excellent example of the 'systems' approach to complex research problems employed by CSIRO
- APSIM, and other DSSs, has struggled to achieve widespread adoption by farmers and their advisors
- To overcome this, CSIRO has engaged in extensive research on farmer decision making, which according to CSIRO has generated considerable benefits. A significant investment made by CSIRO in exploring the application of simulation modelling to farm decision making was in the FARMSCAPE program. Benefits reported by CSIRO stemming from FARMSCAPE include:
  - Increasing farmer adoption nationally of soil moisture and nutrient monitoring to depth
  - Increasing industry acceptance of crop modelling as an diagnostic and decision aid
  - Promotion of the use of seasonal climate forecasts as important inputs into crop production decisions combined with stored soil moisture measurements
  - Diagnosis of important production constraints and elucidation of practices to increase yield and lower risks
- Yield Prophet®, an on-line risk management service based on APSIM, has been commercialized in conjunction with the Birchip Cropping Group (BCG). Subscriptions to this service have been increasing since its introduction in 2002
- However, at present it appears that the majority of the value of APSIM is generated when used by researchers to identify opportunities, constraints and risks, and ways of managing them and extending this knowledge to growers. Moreover, modelling has been extensively used by researchers to better prioritise research investments by allowing the testing of hypotheses through modelling rather than solely in field research
- Specific examples of where this value has been realized and more importantly how ASPIM creates value are:

- Demonstrating that mungbean production is profitable in northern Australian cropping areas when sown in spring with good soil moisture
- Demonstrating that canola can be a valuable and profitable crop in northern cropping rotations

APSIM and the suite of other agricultural based decision support tools developed by CSIRO are good examples of the systems approach to complex problems so often employed by CSIRO.

H.1 Introduction

This case study has been prepared to demonstrate the multidisciplinary 'systems' approach deployed by CSIRO in response to complex research priorities. This analysis of the likely impacts of the use of APSIM, and its associated research, draws on journal articles, provided by, and predominately authored, by those involved in the development and use of APSIM.

CSIRO has stated:

> APSIM is a modelling framework with the ability to integrate models derived in fragmented research efforts. This enables research from one discipline or domain to be transported to the benefit of some other discipline or domain. It also facilitates comparison of models or submodels on a common platform. This functionality uses a "plug-in-pull-out" approach to APSIM design. The user can configure a model by choosing a set of submodels from a suite of crop, soil, and utility modules. Any logical combination of modules can be simply specified by the user "plugging in" required modules and "pulling out" any modules no longer required. Its crop simulation models share the same modules for the simulation of the soil, water, and nitrogen balances. APSIM can simulate more than 20 crops and forests (e.g., alfalfa, eucalyptus, cowpea, pigeonpea, peanuts, cotton, lupin, maize, wheat, barley, sunflower, sugarcane, chickpea, and tomato). APSIM outputs can be used for spatial studies by linking with geographic information systems (GIS)

APSIM is one of a range of simulation models and agricultural decision support tools produced by CSIRO. Other decision support tools include:

- GrassGro – management of temperate grazing systems
- GrazFeed – estimates animal production
- WaterSense – a web tool for irrigation management
- IrriSatSMS - irrigation water management by satellite and SMS

Figure H1 illustrates the systems approach, with the multidisciplinary contributions outlined across the bottom of the diagram. The on-farm research cycle, occupying the top half of the diagram, shows how the simulation modelling research draws on CSIRO's on-farm field research and farmer's own experiences to continuously improve the models and their outputs.

Figure H1 **A frame work using models in farming systems research**

Source: (McCown, Carberry, Hochman, Dalgeliesh, & Foale, 2009)

APSIM has a long history of CSIRO investment. The current APSIM software and supporting services are the result of over 25 years of collaborative research on simulation and adoption research undertaken by CSIRO, the Queensland Government and the University of Queensland under the banner of the Agricultural Production Systems Research Unit (APSRU).

H.2 A brief history of APSIM

The development of APSIM began with the formation of APSRU (Keating, et al., 2003). The initial stimulus to develop APSIM came from a perceived need for modelling tools that could provide accurate predictions of crop production in relation to climate, genotype, soil and management factors, whilst addressing long-term resource management issues in farming systems (Keating, et al., 2003). At this point in time, perhaps the most important failing of simulation models was a lack of a 'systems' approach to crop and pasture production (Keating, et al., 2003).

Prior to the development of APSIM, production models dealt with single crops or seasons and could not cope with longer term effects. They were also based on variable software engineering standards.

Farm decision support tools and modelling had also been largely conducted in Australian in isolation, making the research fragmented. The formation of APSRU brought together a range of organisations to work collaboratively to improve modelling capability and address the lack of 'systems' simulation in current models.

However, the adoption of early versions of APSIM and other DSS tools outside the research community was poor. Farmer and advisor resistance was at the time seen as a major problem due to many attributed reasons, including perceptions of accuracy and a generally low uptake of computing technology by farmers. This low adoption by farmers appears to persist today:

> The idea that simulation models of agricultural production can serve as tools for farmers remains a compelling idea even after 3 decades of mostly disappointing development efforts (McCown, Carberry, Hochman, Dalgliesh, & Foale, 2009)

In response to this lack of early adoption, CSIRO invested in understanding the role simulations models may play in farm decision making and how the information produced by these models could be used by farmers. This formed the basis of the investment in the FARMSCAPE program.

> It [FARMSCAPE] initially involved research to explore whether farmers and their advisers could gain benefit from tools such as soil characterisation and sampling, climate forecasts and, in particular, simulation modelling. Its current focus is facilitating the implementation of commercial delivery systems for these same tools in order to meet industry demand for their access (Carberry, et al., 2002).

FARM SCAPE is an acronym for Farmers, Advisers, Researchers, Monitoring, Simulation, Communication And Performance Evaluation. It is a program of participatory research with farming communities in Australia (Carberry, et al., 2002). The aims of the FARMSCAPE project were:

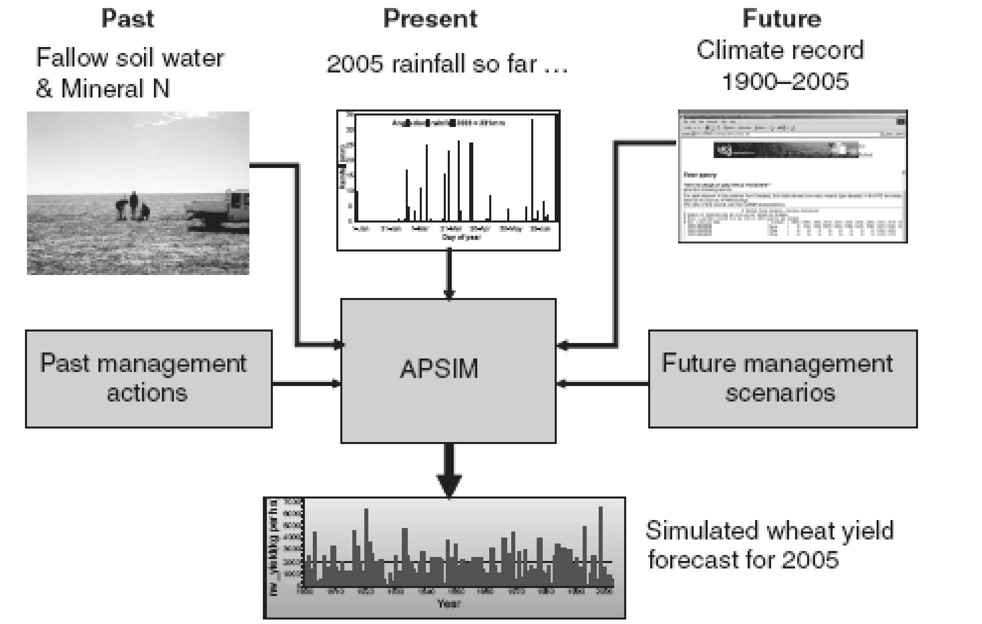
3. To develop networks of farmer groups, facilitated by consultants, advisers or extension officers to engage in on-farm monitoring of soil water and nitrogen; and to train the facilitators in the use of the simulator (APSIM) to add value to data and aid discussion.
4. To find cost-effective ways for farmers, advisers and researchers not in active groups to benefit from the output of aim 1.
5. To evaluate the impact on participants of the co-learning and communication activity (Carberry, et al., 2002).

FARMSCAPE established a direct working relationship between the researchers and over 230 farmers, organised within 28 groups working with 15 farm advisers. The project ran over 30 on-farm trials centred on 13 climate stations in northeast Australia. All crops monitored within the project were used to test APSIM simulations (Carberry, et al., 2002). Simulation with APSIM was a key tool in the program, being used for research analysis and diagnosis, co-learning with decision makers who were actively involved in the project and decision support for the wider farming community. Section H.6.1 contains a discussion of the benefits of FARMSCAPE.

One of the lessons from FARMSCAPE was that such intensive effort by scientists to engage with their clients was time consuming and expensive (Hochman, et al., 2009).

To reduce the cost of engagement with farmers and to assist farmers gain access to APSIM, a simpler and flexible web-based tool, Yield Prophet®, was developed in 2002 – see www.yieldprophet.com.au. Yield Prophet uses APSIM to combine historical production factors such as the length of fallow and soil water and N profile with rainfall to date, and future climate forecasts based on historical records. This process is illustrated in the following figure.

Figure H2 **Schematic representation of the process of in-season crop yield forecasting**



Data source: (Hochman, et al., 2009)

In its first year, the Yield Prophet® reports were based on three representative sites and disseminated by fax. As interest from farmers increased, individual reports were offered for a fee but based on estimated field conditions for each farmer (Hochman, et al., 2009). However, this led to a reduction in accuracy and required the use of actual data collected from the paddocks nominated by the farmer to improve accuracy. This accuracy improvement was facilitated when Yield Prophet® was developed as a web-based tool, which allowed farmers to enter their information directly and produce an automated APSIM report.

However, while much of Yield Prophet® is automated, it also requires considerable support in areas of field monitoring, scientific support to ensure APSIM is updated and reports validated, and assistance with interpretation of the results.

H.3 Current status

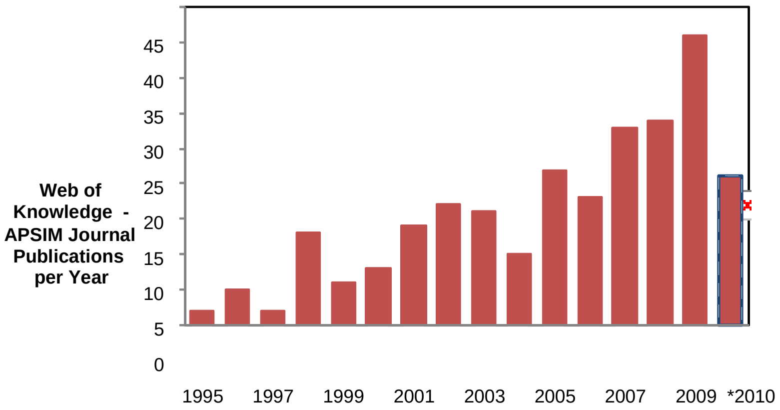
The way APSIM is used in its current form is a product of CSIRO's investments in better understanding farm decision-making processes and CSIRO's modelling and simulation capability. CSIRO has researched how farm decisions can be helped with simulation modelling that highlights prospective points of intervention.

Today:

- There are over 400 APSIM licenses issued worldwide
- Over 40 modules are included in the APSIM framework covering a range of crops, pastures, trees, soil processes, livestock production, management options (e.g. irrigation, fertilisation)
- The software design is constantly being updated, tested and verified. Supporting documentation is also being constantly revised
- The capability is currently underpinned by three full time equivalents (FTE) of software engineering effort and many FTEs of scientific input both from within and outside CSIRO
- While adoption by farmers and advisors of APSIM has been low, adoption by researchers is expanding. Assessing of the benefits of APSIM, based on direct adoption by farmers alone, can give a misleading impression of the impact of a tool such as APSIM.
- Adoption of the information produced by APSIM and distributed through a variety of channels, including researchers provides a better assessment of the value of the model and supporting research.

There is evidence of the rapidly widening adoption of the APSIM farming systems simulator as a research tool. The scientific uptake of APSIM (as roughly indicated by ISI Web of Knowledge) has increased steadily over time. CSIRO has advised that in 2009-10 there was a sharp jump in the number and diversity of scientific papers employing APSIM. Since January 2009, 63 APSIM-related papers have been published, with 30 non-CSIRO lead authors from 19 countries. APSIM-related papers received well over 500 citations in 2009 alone (see graph below).

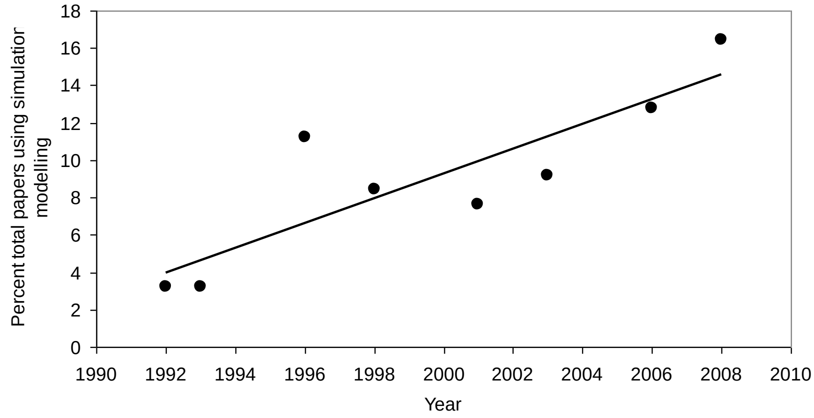
Chart H1 **APSIM citations**



Data source: (Carberry per comm. 2010)

APSIM has been increasingly accepted as a research tool by the research community in Australia (Chart H2) and around the world.

Chart H2 **Time trend of modelling papers as a percent of total papers presented at the Australian Agronomy Conference between 1992 and 2008**



Data source: (Robertson & Carberry, 2010)

H.4 Commercialisation

APSIM is able to be downloaded from the web. Fee-for-service training is offered to users on a regular basis.

Licenses are issued free of charge to organisations and individuals who intend to use the model to produce 'public goods' (R&D, extension and education). Intended commercial users of the software are required to pay a licence fee.

In early 2010, a new unincorporated joint venture for the ongoing development and management of APSIM was formed. The partners to this joint venture are CSIRO, Queensland Government, and the University of Queensland. However, other parties are being encouraged to join this joint venture.

As noted above, one of most significant commercialization opportunities that have emerged from the APSIM and FARMSCAPE research has been the web-based tool Yield Prophet®, providing an internet-based service that allows farmers and their advisors to explore tactical management options with their grain crops in "real-time" ash the potential to be a valuable farm resource. CSIRO has entered into a joint venture agreement with the Birchip Cropping Group (BCG). Yield Prophet® is now in its 5th season with considerable reach across Australia.

H.5 Demonstration of CSIRO capabilities

The CSIRO core competencies contributing to APSIM (and simulation modelling more broadly) appear to be:

- A systems approach to agricultural production systems and resource management
- Coordinating extensive on-farm experimentation, extension activities and simulation modelling capabilities
- Computer based simulation modelling skills
- An understanding of farmer decision making, approach to risk and the role of decision support

Agricultural simulation modelling, as with most economic or process models, assembles and replicates the interaction of a wide range of variables simultaneously. This modelling approach can have high powers in capturing the way variables interact, but perhaps the most powerful aspect of models such as APSIM, is their ability to assess the effects of permutations to a system.

However, application of a simulation model requires considerable data and a keen understanding of the system it is simulating. CSIRO maintains this capacity through its extensive investments in livestock, plant and soils research, and software engineering. These investment, when combined with its wide spread engagement with farmers (particularly through FARMSCAPE) has enabled CSIRO to develop simulation modelling and constantly improve its accuracy and applicability.

APSIM underpins much of the research being managed under the new CSIRO Sustainable Agriculture Flagship.

H.6 Key benefits emerging from the work

Overall the impacts of CSIRO's investment in APSIM, and associated extension and adoption investments to support it, appear to have produced considerable benefits for agriculture. They can be summarised as:

- Developing a greater understanding of the key production risk factors in crop and livestock production in Australia; and how these risks can be managed
- Providing farmers with tools to prioritise data collection (such as measured plant available water and key nutrients such as N in the soil profile)
- Providing a set of tools to interpret the field data collected and simulate a range of 'what if scenarios' using historical regional climate records

Some of the more specific impacts of the extensive investments made by CSIRO in this area are listed in the sections below.

H.6.1 FARMSCAPE impact

Section H.2 contains a history of FARMSCAPE and its relationship with APSIM. This section outlines some of the benefits produced by FARMSCAPE.

The investment in FARMSCAPE, to support the adoption of systems simulation, led to a series of impacts that can be summarised as:

- Improved awareness and adoption of deep soil monitoring (nutrient and stored plant available water) as a key management practice. This has influenced farmers and advisors by :
  - Demonstrating value in better knowledge of soil resources to depth.
  - Designing and developing inexpensive soil coring equipment for use by hand or using hydraulics, and arranging for two local manufacturing companies to build and sell this equipment
  - Writing and publishing the 'Soil Matters' manual (Dalgliesh and Foale, 1998) which contains information on sound procedures to sample soils and interpret results for distributiion to farmers and agribusiness.
  - Actively promoting these technologies through industry-sponsored publications and events to encourage wider uptake and use
- Increased industry acceptance of modelling. Indications of this include:
  - The establishment of a commercial FARMSCAPE Training and Accreditation program, in which four agribusiness companies paid to participate and be trained in using APSIM within their commercial advisory services. This program was designed and initiated through active industry support and sponsorship (see section on FARMSCAPE phase II)

  - Industry-led conferences, update meetings and training courses now actively incorporate simulation modelling as a key component to their programmes – examples include dryland cotton pre-season planning meetings, grains industry annual update meetings, accredited agronomist courses for chickpea and mungbeans, and so on
  - Direct sponsorship of the FARMSCAPE team and its activities by two agribusiness companies
  - Expressions of interest from farmer groups throughout Australia for replication of FARMSCAPE interactions for their own regions, particularly in accessing APSIM simulations
- Development and promotion of the model for the use of seasonal climate forecasting
- Innovative changes to farm practices as a result of modelling feedback (see canola and mungbean examples below)
- Highlighting to farmers the potential improvements to water use efficiency that they could gain and the resultant improvements in yield that would result

H.6.2 Some of the impact of Yield Prophet®

While is difficult to demonstrate the impact of Yield Prophet® on farm decision making, its adoption by growers provides some indication that it is seen as a useful tool for cropping managers. The following table shows the growth in Yield Prophet® subscriptions between 2002 and 2007:

Table H14 **The growth of Yield Prophet®'s subscriptions and usage from 2002 to 2007**

	2002	2003	2004	2005	2006	2007
Subscribed fields	5	29	50	356	550	558
Consultants	1	1	3	37	37	50
State government /researchers	0	0	2	5	8	21
Reports produced	7	260	1200	6800	8300	9200

Data source: (Hochman, et al., 2009)

H.6.3 APSIM impacts

In summary CSIRO's investment in APSIM and associated management decision support research benefits farmers and researchers. These benefits include:

- Improved farmer and researcher understanding the management of farm resources in particular soils

- For those farmers using APSIM or a web based interface using ASPIM such as Yield Prophet®, better on-farm prioritisation of management interventions
- For the increasing number of researchers, and research managers using APSIM, a potential reduction in the level of field experimentation required and/or improved prioritisation of research investments – possibly rendering previously unjustifiable R&D cost effective and delivering earlier access to outcomes
- For the grains and livestock industries generally, a potential bringing forward of innovations because some early-stage research station and field trials can be avoided or abridged by using simulation modelling to pre-test hypotheses
  - A potential for substantial improvements in farm risk management as farmers can simulate a range of potential negative shocks on their businesses and determine the most appropriate risk management strategies including responding to climate change and changes to climate variability

The major factor limiting private benefits generated from most simulation models is adoption – an issue that has been identified widely in the literature. However, productivity gains for individual businesses which use these tools could be large. APSIM also now has a broad application base, over different formulations and types of application, affording scope for overhead sharing of the core system even where take-up of individual applications is modest.

The public benefits that could be generated from this type of simulation modelling include improved management of water and soil resources – with natural links into sustainable agriculture. This could also be extended to greenhouse gas management – APSIM may well have significant potential in addressing the impediments to accounting for soil carbon (as discussed under the biochar vignette).

Modelling capability is often a critical enabler of market based and other policy instruments dealing with the allocation and management of scarce resources and externalities – such as in relation to water or GHGs. Agricultural and land use systems modelling has been identified by ACIL Tasman as a critical initial step in several recent policy development processes such as:

- The management of water interceptions in the landscape and their impact on extractive water users and environmental flows
- Incorporation of agriculture into carbon mitigation policy, including via voluntary offsets markets

H.6.4 Some specific examples of the use of APSIM and its impact

The following case studies are examples of the types of impact APSIM has had. They should not be construed as a demonstration of the total or even a significant portion of the value of APSIM as this has been discussed in preceding sections.

These case studies have been included to provide a tangible demonstration of one of the ways in which APSIM is applied and the results that stem from the application. In these case studies the application of APSIM can be summarised as:

6. Identification of possible options through simulation of scenarios
7. Testing the new practices with innovative farmers and advisors
8. Monitoring the management and performance of commercial crops and comparing yields with benchmarks estimated with the model

Two examples of the use of APSIM to investigate farm management changes and new crop options in the southern Queensland and northern NSW regions are mungbean and canola. Each is discussed in more detail below.

H.6.5 Canola

Canola production has increased dramatically in the southern grain growing areas. Current annual production is approximately 1.0 to 1.2m tonnes per annum in favourable years.

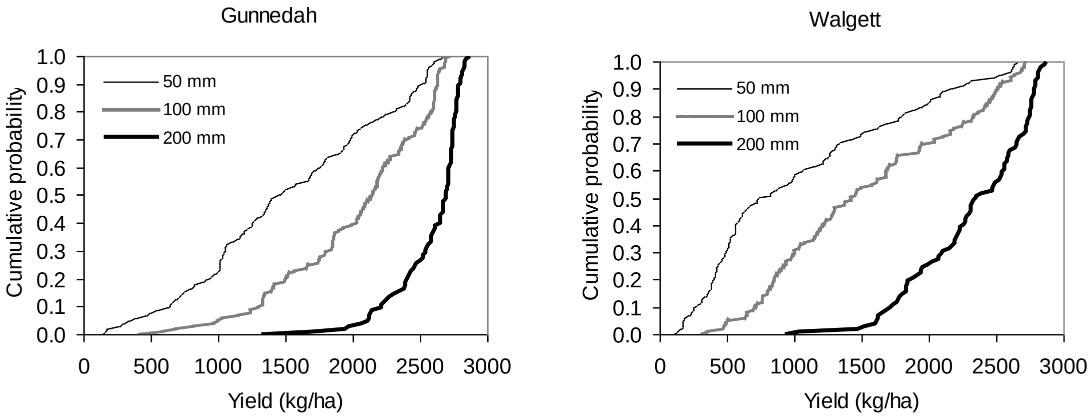
Canola, from the Brassica family, has also been a good disease break crop in cereal rotations and allows a range of alternative chemical weed control options to cereals. The advent of Roundup Ready GM canola has also introduced another important weed control option in crop rotations.

However, despite these rotational advantages, canola has not been included in northern crop rotations as extensively as in the south. The limited adoption of canola in the north is largely due to higher variability of rainfall in this region compared to the south and canola's lack of dry period tolerance compared to cereals.

CSIRO used APSIM simulations of canola production in the northern wheat belt to identify and develop strategies to reduce the risk of growing canola in the region (and to test the suitability of a close relative of canola Indian mustard which is far more drought tolerant).

The results of the simulation modelling showed the sensitivity of the crop to soil moisture at sowing based on 103 simulated seasons (see Chart H3).

Chart H3 **Cumulative distribution functions of grain yield for different levels of available soil water at sowing for a reliable (Gunnedah) and marginal (Walgett) canola production area in northern NSW. Each composed of 103 simulated seasons (1990-2002)**



Data source: (Holland J. , Robertson, Wratten, Bambach, & Cocks, 2003)

The APSIM simulations in Chart H3 show the probability of achieving certain yields, with 50, 100 and 200mm of stored moisture at sowing it Gunnedah and Walgett. The slower the rise the slope the less likely yield increases will be.

The rainfall years were then grouped according to April-May SOI trends. The results of the SOI affect are shown in Table H15. These results suggest a higher probability of a higher grain yield and gross margin in years when the SOI in April to May is neutral to positive.

Table H15 **Long term average (1990-2002) simulated grain yield, oil content and gross margin by April-May SOI phase for Moree. Simulations assumed 100mm available soil water at sowing**

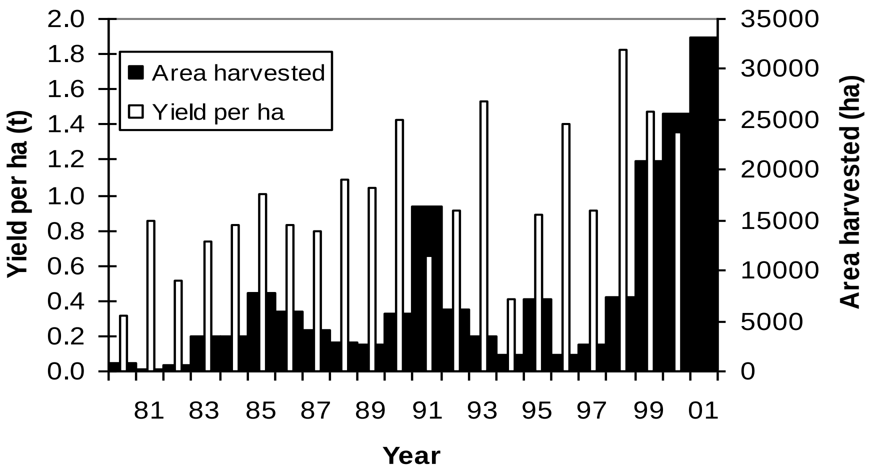
SOI Phase	Number of years	Grain yield	Oil content	Gross margin
		(kg/ha)	(%)	($/ha)
Negative	16	1449	39.0	77
Positive	22	1797	40.7	86
Falling	14	1289	38.1	82
Rising	26	1898	40.6	100
Zero	25	1741	40.2	101
All years	103	16886	39.9	91

Note: Assuming a grain price of $350/t and variable costs of $200/ha

Data source: (Holland J. , Robertson, Wratten, Bambach, & Cocks, 2003)

The results of the modelling provided growers with sufficient confidence to trial canola under certain conditions and in certain areas. It also allowed growers a quantitative assessment of the risks and rewards of canola production that was not available in the past without expensive commercial trialling of the crop.

Chart H4 **Area and yield of canola in northern cropping areas of NSW and southern Queensland**



Data source: (Holland J. F., Robertson, Cawley, Thomas, Dale, & Cocks, 2001)

Chart H4 shows the steady growth of canola yield and area between the early 1980s and early 1990s. Between 1990and 1997 canola areas and yield stopped increasing. The data in the chart then shows a marked increase in area and yield between 1995 and 2001.

H.6.6 Mungbean

In mid 1990s CSIRO began a series of simulations and trials looking at the optimum time for sowing mungbean. At that time farmers perceived mungbean as being a low yielding, high risk crop. Due to this perception, farmers were planting mungbean following winter cereals, essentially as an opportunity crop to utilise residual soil moisture and take advantage of summer rainfall should it occur. This practice meant that the mungbean was being planted on suboptimal soil moisture and were susceptible to heat stress over summer. This practice created negative, and self-fulfilling, experiences with the crop.

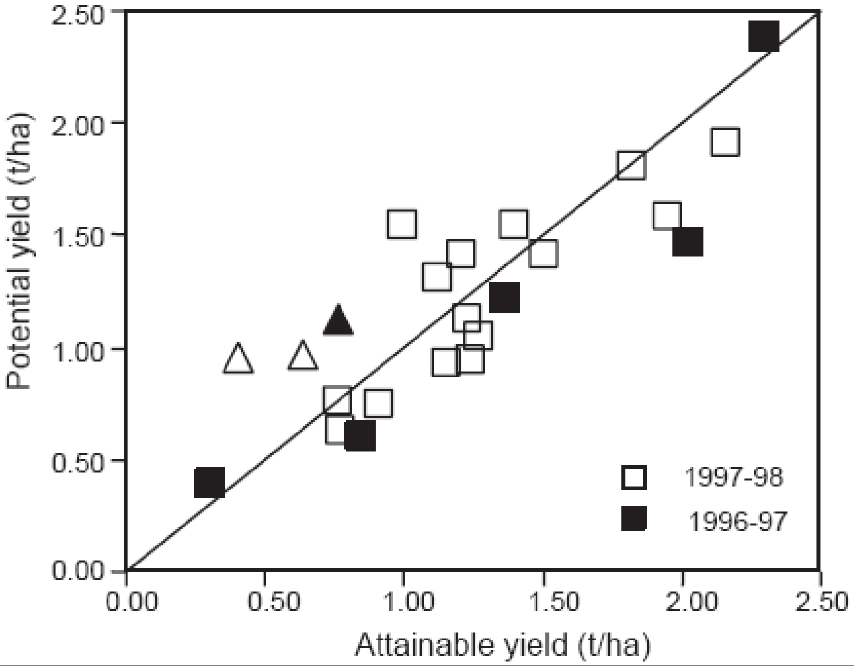
CSIRO APSIM simulations showed a strong relationship between available soil moisture at planting and mungbean yield. This modelling also showed that yields and gross margins could be increased if the crop were sown earlier.

Prior to 1996, all crop research trials investigating planting time effects on yield excluded planting before October. APSIM modelling using historical annual monthly rainfall showed that yields could be increased if mungbean was sown on good soil moisture in September. As the beans would be harvested in December, a long summer fallow would allow the accumulation of soil moisture prior to the planting of the winter cereal the following year.

This APSIM modelling was refined with the help of, growers, agronomists and grain traders. This exposure to, and working with, the model gave these participants the confidence to trial spring sowing mungbeans.

By closely working with farmers and their advisors the accuracy and the applicability of the model was able to be demonstrated to them. Plotting actual yields achieved in the plots (attainable yield) against model simulations yielded a good statistical fit (see Chart H5).

Chart H5 **Potential (simulated) yield v attainable yield (quadrat) for the spring-sown crops grown in 1996-97 (n=6) and 1997-98 (n=19)**

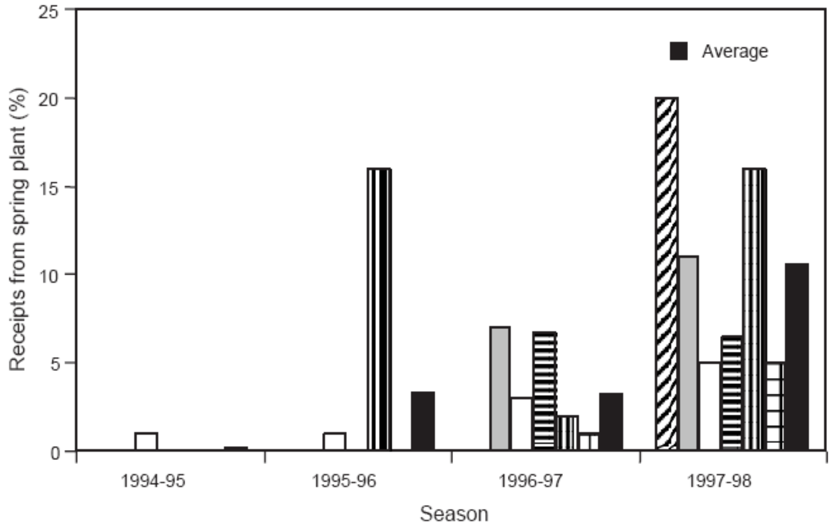


Data source: (Robertson, Carberry, & Lucy, 2000)

Note: Points with the triangle symbol had a significant discrepancy between the potential and attainable yields (see text for discussion). Also shown is the 1:1 line.

The yield improvements and extension of the results by CSIRO, QDPI and commercial agronomists contributed to an increase in spring sown mungbean production from virtually zero in 1994-95 to 25 per cent of total mungbean receipts by traders in 1997-98 (see Chart H6).

Chart H6 **Percentage of total seasonal receipts that came from spring-sown mungbean crops, over the 4 growing seasons 1994-95 to 1997-98**



Data source: (Robertson, Carberry, & Lucy, 2000)

Since 1996, mungbean production has grown from an area of 20,000 ha to over 52,000 ha. Current mungbean production is approximately 39,000 tonnes with a net value of $7m per annum.

H.7 Emerging risks/issues

Critical to the continued development of simulation modelling is an improvement in adoption of, or the use of modelling outcomes, by farm business managers and/or their advisors.

Farmers have been resistant to using APSIM themselves but the experience of Yield Prophet® suggests that increasingly farms may be willing to use web based DSS tools driven by APSIM applications

Agriculture and other land uses are entering a period where real time, sophisticated data collection is occurring at an increasing number of points in the farm system. Yield and quality monitoring of crops, pastures and forests is increasingly being integrated to sowing, harvest, spraying and other farm activities. This is likely to reduce the barriers to entry of commercial simulation modelling products and provide a far more comprehensive data source for APSIM

H.8 Why CSIRO is investing in systems modelling research and development?

The material provided by CSIRO which forms the basis of the case studies contains information which demonstration of considerable value produced by

APSIM and associated decisions support research. However, a critical questions for the counterfactual is what value would have been created had CSIRO not invested in these models or alternatively curtailed its investment in this area. That is, how additional is the value created by CSIRO?

While it is not possible to comprehensively answer this question given the scale of this case study, there are indications that CSIRO's investment would not have otherwise been made by industry or others. This is due to:

- The high cost of collecting large amounts of field data to validate models which is beyond the capability of farmers, advisors and other even other industry or state based research organisations
- The until recently, low up take of computers in farm businesses
- The high transaction costs associated with assembling and coordinating the large multidisciplinary teams that are required to develop and verify farm production system models
- The associated need to spread the high development costs of such a diverse application base.

I Murray-Darling: Policy & Strategy Support

In ACIL Tasman's 2006 review, the then relatively new Water for a Healthy Country Flagship (WfHC) was the subject of reasonably detailed case study. The Flagship involves investment of the order of $90 million per annum, accounting for about half of total Australian investment in water research.

We have not attempted a comprehensive update here. Instead, we have assembled a brief review of recent developments and their likely implications – and have focused on one specific vignette in relation to the Murray-Darling Basin Sustainable Yields Project. It is not a full-blown case study – but does provide some insights into the delivery of substantial value, drawing heavily on existing CSIRO capability and leadership.

It is notable that this very high profile project was not even considered in the last investment – though the core capabilities deployed in the project were clearly recognised as offering high option value given the stresses on the water systems. In particular, our assessments of CSIRO's engagement in relation to three themes: the Murray River Region; Australian Water Resources; and the Water Resources Observation Network. These themes all dealt with core capabilities that have since been directed into the Murray-Darling Sustainable Yields Project.

At the time of the last assessment, we developed what we saw as highly conservative assessments of the value of these three themes within the Flagship that totalled over $700m. These were values attached to opportunities we then saw to drive greater value from limited resources relative to a strong counterfactual covering what would happen without CSIRO's involvement. They did not take into account the new policy platform that emerged with the change of Government or the scale of early commitment of Government funds.

This very evolution of the structure of the Flagship's work has been informative as a demonstration of the way that investment in a strong capability base, guided by realistic assessment of emerging needs, can underpin the flexibility to adapt to rapid changes in demands for analytical and advisory services relevant to the roll-out of a major policy shift and expenditure program.

Since our last report, the scale of emphasis given to Government investment in the Murray-Darling Basin has intensified substantially. Passage of the Water Act 2007, the change of Government in late 2007, the Water for the Future Plan and the continued deep drought conditions in especially the Lower

Murray-Darling Basin[46] have combined to create a platform in which the potential immediate value in the capabilities being developed by CSIRO was dramatically higher than we had previously assumed in our conservative assessment. These developments have also brought forward a greatly heightened demand for CSIRO services as part of a major national policy development process.

Against this background, review of the impact and value of CSIRO's involvement in Murray-Darling Basin planning makes sense as a way of probing the value of these parcels of 'deployable, multidisciplinary capability' and capacity for large-scale rapid response to new policy needs, especially in the context of new Government commitments to large-scale funding of water buy-back and water efficiency investments, and the establishment of the office of Commonwealth Environmental Water Holder, as the manager of a large, high value and high opportunity cost portfolio of water assets, where even modest improvements in portfolio management could yield high value.

The work also serves as a demonstration of CSIRO's ability to manage a very large scale project, in tight timelines, that involves expertise drawn from a wide range of agencies and professional firms – to deliver outcomes that support not just immediate objectives but that have again laid down a foundation of options for future value generation.

I.1 Context

In November 2006, the Council of Australian Governments appointed CSIRO, via the Flagship, to lead the Murray-Darling Basin Sustainable Yields Project. This was done in the context of a range of factors combining to create unprecedented concerns for the sustainability of the Basin:

- Prolonged drought of unprecedented severity across significant parts of the Basin, especially the Murray-Murrumbidgee system;
- Trends that had involved increased land development and associated water use, including growing demands for water for urban, industrial and commercial use, as well as irrigation use;
- Consequential rapid reassessments of the reliability of the resource and the nature of the resource management that was appropriate – including serious consideration needing to be given to risks of loss of system supply capacity to Adelaide and of loss of the ability to sustain some major ecosystems;

[46] The prolonged nature and unprecedented depth of the drought has also added empirical support to the concerns that there has been a structural shift in regional rainfall, as a result of climate trends – paralleling the longer term structural pattern seen in the South-West of Australia since the mid-1970s.

- Growing acceptance of the risks of structural change in rainfall patterns and inflows as a result of climate trends – in which risks of more frequent prolonged and deep droughts were seen as a major challenge;
- Growing conflicts over the management and allocation of water: across uses and jurisdictions; between short term use with known very high value and stewarding of the resource for future use with high value in the event of the drought conditions persisting; between ecosystem values and active extractive uses.

These developments challenged deeply the assumption that there was a resource with broadly understood hydrological properties that could allow for sensible resource management. The very concept of a 'sustainable yields' project reflected the recognition that it could no longer be assumed that the safe levels of water use were known.

At the same time, the trends in water availability, combined with the operations of water markets, were demonstrating levels of market value in water that could be directed to alternative uses much higher than had traditionally been assumed. This in turn was suggesting that the economics of investment in improving water use efficiency, and in better managing the allocation of water across uses, warranted a major reassessment. The timelines, with emerging risks of major disruption in supplies to some uses and ecosystems, and risks of essentially irreversible damage, added urgency to policy development that was unprecedented.

The Murray-Darling Basin accounts for about 40 per cent of the gross value of all agricultural production in Australia (ie, of the order of $16 billion annually), with this value being heavily underpinned by irrigation and massive sunk investment in irrigation infrastructure. By 2006, much of this infrastructure was looking a lot less valuable than had previously been thought the case.

Urban growth in towns along the rivers, and Adelaide's demand for water, were fuelling competitive demands for water supply – and constituted high value demands for water supply, given the emerging costs of alternative supply systems. The reliability of the Snowy Hydro Scheme, a major component of Australia's renewable energy production capacity, was being challenged by limited supplies at the same time that alternative thermal generation capacity was facing growing concerns with access to water for steaming.

In parallel with these developments in relation to extractive uses of the water, there was growing awareness of the emerging, and in some cases potentially imminent, threats to high value non-extractive uses – including recreational, amenity and ecosystem values along the system, and especially in the Lower Murray-Darling Basin.

All these forces helped to shape the demand to better understand the resource and the longer term options for use of the resource, in environmental and extractive uses.

Essentially, the Project was to develop an assessment of all the available water within the Basin – factoring in likely changes in climate, catchment development and groundwater extraction out to 2030. This meant it was not about documenting the water already in the system, but rather documenting the credible variations in water within the system, given likely climate and development trends. The exercise was essentially probabilistic in nature, recognising that outcomes would be heavily driven by the unknown pattern of rainfall over the next 24 years, in the context of much greater uncertainty about predicting even the propensity for drought than had previously been assumed.

The Project budget was about $12 million, but this did not factor in the large in-kind contributions that would be made by agencies across the country with a shared interest in building this understanding.

At the Federal level, the extreme circumstances had led to an almost bipartisan agreement on the need for radical change in the way the system was being managed. This recognition was in fact a contributor to the COAG commitment to the project. However, the change of Federal Government in late 2007, half way through the life of the Project, brought with it substantial changes in actual policy approach – changes that almost certainly added a lot to the immediate value of the work being done.

- The Water for the Future Plan committed $12.9 billion over 10 years to drive better, and sustainable, water resource management and to assist communities experiencing pressures from resource changes. Key relevant components, announced in the 2009 Budget, include:
  - $5.8 billion, via the *Sustainable Rural Water Use and Infrastructure Program*, for improving the efficiency of water systems, with water savings to be shared between extractive uses and the environment
  - $3.1 billion, via the *Restoring the Balance to the Murray-Darling Basin Program*, to buy back extractive water rights from willing sellers for reassignment to the environment.
  - Investment of $450 million, via the *Improving Water Information Program*, in better monitoring, assessment and forecasting of the resources.
    - … We note that in 2008 the Flagship entered into a $50m, 5 year water information research and development alliance with the Bureau of Meteorology.
  - Expectations that the funds will leverage around $10 billion in funding from other sources
- Oversight of the Murray-Darling Basin management was transferred to a new Authority, with a key focus on urgent development of a new Basin

Plan to set new sustainable limits on water use and to shape the overall development of Basin strategy.

We also observe that, since the change in Government, the Commonwealth Environmental Water Holder, a position established by the Water Act, 2007 has commenced operations. The responsibility of the office includes use of its holdings of water (including water bought back from the Murray-Darling system) to protect or restore environmental assets in the Basin. The 2009-10 Business Plan for the office has specified as the leading priorities:

- Avoiding the loss of threatened species
- Avoiding irretrievable damage or catastrophic events, and
- Providing drought refuges to allow recolonisation following the drought.

A recent Productivity Commission report has challenged the current balance between buyback and water efficiency infrastructure investment, suggesting that there would appear to be scope for achieving far greater value for money through rebalancing towards buyback.

We document this background because of what it says for the potential 'application base' for a better understanding of the Murray-Darling system and its threats and capacity. A modest improvement in the effectiveness with which these resources are allocated offers the potential for very substantial gains – including avoidance of unnecessary costs and limitation of exposure to risks.

I.2 CSIRO's contribution

The project was a large-scale team effort. In total, it involved more than 170 people from 15 organisations. Of these, about 60 were CSIRO researchers. It drew on 40 existing models of components of the Basin system, and an additional 30 new surface and groundwater models developed to fill strategic gaps in the coverage. There was a need to build key linkages between surface and groundwater across much of the system. The existing models were not consistent in approach, so substantial effort was needed to adapt them, within a sound framework, to produce coordinated coverage of the entire Basin, from which a 'super-model' was developed. This created a capability that had not previously existed – the ability to consistently and seamlessly model flows from one end of the system to the other under a wide range of forward climate scenarios.

The initial weaknesses were particularly pronounced in relation to the largely unregulated Darling system – whose role and significance grew as pressures on the lower Murray-Darling system developed across the life of the project.

The simulation capability of the model was augmented by a set of whole-of-basin climate forecasts and scenarios – drawing significantly on broader CSIRO capability in developing regional climate forecasts. Three IPCC-agreed global warming projections were modelled using fifteen Global Climate Models and four water resource development scenarios are built into the model. The model is structured to support detailed consideration of distributional effects across 18 regions.

The result was an integrated model and simulation capability that is being heavily used by the Murray-Darling Basin Authority to underpin its Basin Plan – one of the central planks of the Federal Government's water strategy.

It was the largest single project ever undertaken by CSIRO and was arguably the largest and most technically challenging water modelling project ever undertaken in the world.

The resulting system, and requirements for iterative simulation, with spatially resolved patterns of flow at a fine regional level, meant that running of the model was extremely intensive of computing resources. This was not a model suited to running in a PC environment. CSIRO was in a position to offer access to the scale of computer power that would have been difficult, and certainly slower, riskier and less cost effective to achieve otherwise. Indeed, continued access to CSIRO's computers remains a feature of the capability that has been developed. In time, it will probably make sense for key organisations, including the Murray-Darling Basin Authority, to explore other ways of supporting access to the modelling capability – but immediate access to capability on this scale was an essential feature of the capability offered by CSIRO, given the approach adopted.

Had this not been possible, a modified approach, entailing a range of simplifying assumptions would almost certainly have proven necessary – and probably pragmatically sensible. However, it has emerged from the more sophisticated modelling that there are extremely important, and complex, micro-level interactions that would almost certainly have been lost under these simplifying assumptions, for example, under current water sharing rules the environmental is disproportionally penalised under scenarios of reduced water availability. It certainly means that the system now available is a lot richer in its capabilities than would otherwise have been achieved – including options to push the modelling further with substantial confidence.

This said, the fact that the project was bigger than anything that had preceded it – and bigger than possible alternative approaches that might have been adopted – does not automatically mean that it was better or better value for money. It is legitimate to ask if the study was over-engineered.

What the modelling has demonstrated is that hydrological effects are highly sensitive to the detail of the specification. The system is not linear, or amenable to simplifying assumptions that do not risk serious error in small area inferences. The modelling has pointed to substantial variation in impacts across regions and uses that could certainly have been missed or underestimated in the absence of the level of detail enabled by CSIRO's presence. Whether this is translating into substantially different Basin planning is more arguable, but proceeding to plans based on a much simplified approach to the modelling would certainly have entailed much greater risks of systematic bias.

CSIRO clearly led the study throughout. The way in which the different existing capabilities were captured and used required very large contributions from the range of contributing organisations. However, the overall approach and the fusing of the existing work into a practically applicable operating model was heavily dependent on CSIRO capability and leadership.

I.3 Capability options

The creation of this model has delivered powerful tools for focusing the planning for the Basin, a process now being driven by the Authority. However, the CSIRO leader of the Sustainable Yields project has now been seconded into a key role within the Authority – as a way of supporting maximum value being extracted from the work that has been done.

Beyond the Murray-Darling Basin, the approach used has laid the foundation for analogous work in other water systems. Lessons have been carried across to the modelling of 20 developments across northern Tasmania, to reviewing water strategy in relation to SW Western Australia and to assessing water strategy options in northern Australia. The methodology is likely to have international application – though this need not translate into large benefits for Australia.

I.4 The Counterfactual

The project as delivered would essentially not have been possible without CSIRO's involvement. However, the policy process would have continued and would have relied on the analysis that could be achieved without CSIRO's role.

This would entail less sophisticated modelling, with less scope for probing cross-system variability; would have been reliant on less credible climate scenarios at the level of regional detail used; and would have been slower to evolve towards the capabilities now available.

We have spoken to users within the Murray-Darling Basin in testing our understanding of the perceived significance of CSIRO's role. We received strong endorsement for the view that they added very substantially to the capability available for developing Basin Plans – with the resultant Plans now emerging for implementation.

It is harder to argue with certainty that the Plans are dramatically different – but it does seem highly credible that CSIRO greatly reduced the risks of serious error in the planning process. It is also clear that the capabilities of the system to differentiate impacts across the system are much greater than would have been the simpler models – this suggests additional insurance against potentially serious adverse equity as well as efficiency consequences of cruder policy development.

I.5 Value indicators

The above discussion highlights clear impact from CSIRO's involvement. The planning processes have been different, planners have had access to finer detail in modelling and the capacity to distinguish variation in water sharing impacts across the system that would not otherwise have been possible. Risks of locking in costly errors associated with these system insights have been reduced.

Given the strategic significance of the uses and ecosystems tied into the Murray-Darling Basin, the breadth of activity dependent on the Basin and vulnerable to either excessive caution in setting Plans or to the consequence of insufficient caution, and the extent of national awareness of the Basin values, insurance of these types would seem potentially of great value.

Translating such an impact assessment into a dollar valuation is more problematic, and we have only sought, in the context of a vignette, to develop a credibly conservative valuation, based on somewhat stylized assumptions. We focus on the value of better modelling and advice as input to the massive investment process being rolled out in the Basin – through buyback, water efficiency investments, altered Basin Plans and on-going management of the portfolio of environmental water being acquired on behalf of the community. We also note that this is happening in an 'urgent' setting, with options being rapidly constrained as ecosystems are being altered, in some cases effectively irreversibly, as a result of prolonged drought and as many irrigation farmers face tough decisions about possible major changes to farming systems in which there is massive sunk investment.

In this context, the scope for decisions that later prove regrettable is high, and the value of even moderately earlier access to better system modelling could prove very big.

There is understandable questioning of the efficiency of the proposed investment patterns – including in the recent Productivity Commission review. The Commission in particular commented on the undesirability of needing to commence buyback of water ahead of finalising the Basin Plans – further emphasising the value in being able to develop appropriate plans early. There may well be scope for increasing efficiency even with the CSIRO work – but it seems plausible also that additional efficiency is likely to be attainable earlier and more safely as a result of Basin Planning that factors in the extra sophistication delivered by CSIRO.

The Government has committed $12.9 billion over 10 years with expectations that approximately the same amount will be leveraged from elsewhere. These policy commitments have been based on consideration of the options and a clear conclusion that such investment should provide benefits in excess of costs. The nature of the ecosystem and social values at stake strongly suggests that early intervention of the type being undertaken could limit substantially the damage otherwise likely to occur in the system in coming years – with plausible prospects for the benefits from sound strategic investment being many times the costs.

As an indicator, suppose an aggregate $2 billion is to be invested annually over 10 years, with expectations of a stream of benefits ensuing that justify this investment. While the return on this investment at the margin of the proposed funding might have been considered just break-even, the intention was clearly to 'pick the low hanging fruit', with every expectation of benefits, across the social, environmental and economic dimensions, well in excess of costs for most of this investment. We would expect that expectations would be that benefits (mainly in the form of damage mitigation) would be at least several times costs, assessed across the entire planned expenditure.

This assessment is further supported by the scale of the extractive use values of the water supplies, the increasingly appreciated and valued non-extractive values, the severity of the apparent conflict between these and the high uncertainties that existed at a time commitment was being made to urgent investment that would have major implications for these values. Relatively small variations in how these investments are made could plausibly have very high impacts on these large extractive and non-extractive values, on the value of the sunk infrastructure and on the social values linked to the Basin and its water supply, reliability and use.

Suppose then that we take a very conservative position, and assume average benefits just twice costs but in a context of very high uncertainty and risks of irreversible damage. Suppose now that the access to better modelling and simulation capability, and the deeper, consistent understanding of the whole system, supports a 10 per cent increase in the efficiency with which this investment gets deployed – it adds 10 per cent to the present value of returns across environmental, social and economic dimensions of value.

This again seems quite conservative[47]. The qualitative shift in the nature of the modelling advice, the multiple ways in which the advice can influence early decisions likely to lock in serious errors, the insurance 'premium' that might be justified to limit the risks of serious errors that prove irreversible, and the essential way in which the sustainable yields project reshaped our understanding of the Basin system across credible future rainfall scenarios suggest an investment of this type was highly appropriate as an adjunct to the planning and investment processes. We would expect it to entail a high likelihood of a significant improvement in both the Plan and the investment strategy and at least a moderate chance of avoiding very serious and high cost error.

Based on these highly stylized assumptions, and corresponding modelling of Basin values over 30 years, the return on the investment in building this capability would be of the order of $2.8 billion in present value terms.

We doubt that this is a fair indicator of overall value. It is certainly plausible that the figure could be substantially more – should a major 'error' in planning be overlooked, or locked in for excessive time, because of poorer access to information at a time when large, long-lived capital investments are being locked in. We note that the current Flagship goal is to "provide Australia with solutions for water resource management, creating economic gains of $3 billion per annum by 2030, while protecting or restoring our major water ecosystems." Of these figures are not comparable, but the goal certainly implies expectations of some very big impacts.

The opportunities this more sophisticated modelling capability offer to the Commonwealth Environmental Water Holder could also be large, as the size of the environmental water portfolio grows and possibly as pressures on the system continue to evolve.

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[47] We note that Deloitte (2009) pointed to stakeholder consultations that suggested better information could in aggregate improve water investment efficiency by "somewhere in the order of 10 to 30 percent." We further note that the Flagship accounts for about half of all investment and that the relevant figure is not a fair share of overall gains attributable to CSIRO but rather the incremental value delivered by CSIRO's role. For its analysis of the Flagship as a whole, Deloittes concluded that "efficiency gains in the 5 to 10 per cent range could be conservatively expected." The nature and timing of action in the Murray-Darling Basin and complexity of the issues, suggests that this Basin could be more fertile than most for such efficiency improvement through better early information. Deloittes also concluded that efficiency gains from the Flagship as a whole of 2.2 per cent would be enough to cover costs.

$3.1 billion of water buyback has been targeted for the Murray-Darling Basin under the Restoring the Balance in the Murray-Darling Basin program, along with a share of water efficiency savings under the $5.8 billion national spend of the Sustainable Rural Use and Infrastructure program. The downstream implications of regional investments in water efficiency savings, coupled with this level of commitment relative to buyback, does suggest high value in gaining earlier access to better system knowledge. One of the key difficulties with local water efficiencies savings is that they can entail recovery, for local use, of water that would otherwise have been available further downstream in the system – as a result of water flows into groundwater being limited to avoid what are seen locally as losses but need not necessarily be system losses.

We understand that negotiations are under way exploring scope for the Commonwealth Environmental Water Holder to tap directly into this now established CSIRO capability. Some care is needed not to double count – we have already assumed benefits across the entire investment portfolio, including buyback. However, the capabilities for modelling small area effects in a manner that is consistent across the Basin, as offered by the CSIRO capability, would seem well suited to supporting flexibility in the evolution of the Commonwealth Environmental Water Holder's role as needs and responsibilities develop further.

One possibility here is opening up scope for the environmental water portfolio to be traded, at least temporarily, with extractive use water as well as between environmental applications. This capability could create greater flexibility to deliver environmental water to where it has the greatest capability when it has the greatest capability. The approach to modelling used by CSIRO would seem well suited to application in exploring such possibilities. Given that this flexibility has not been built into the present function of the office, we assume these values were not part of the cost justification for the investment that has been committed. In effect, they represent an addition block of options with potentially high value. Our 2006 review flagged a growing literature looking at the potential high values in greater flexibility in trading water between uses and parts of the system across time.

Importantly, the downside in this investment appears actually very low – if we accept that a superior simulation capability has emerged relative to the counterfactual. The counterfactual would still have entailed very significant investment, certainly of several millions of dollars. The potential cost savings would have been at best a few million dollars. As noted earlier, outcomes might have been similar, but the risks with the investment strategy seem likely to have been substantially greater.

Finally, we note that a flow-on from the project has been CSIRO's ability to transfer the capability for basin yields modelling to applications in Tasmania, Northern Australia and South-West Western Australia. This capability to extend it further, as well as to further refine the modelling in specific high value areas or in relation to key policy prospects remains as a source of option value.

All of this reasoning suggests that a conservative valuation of the additional capability brought by CSIRO – inclusive of insurance against potentially very high cost errors – would be comfortably above the $2.8 billion figure developed above. Undoubtedly this is judgmental – the counterfactual has not been run. But the nature of risks involved in the large scale interventions proposed – and the even greater risks in not intervening in the system urgently, given the stresses and risk of irreversible damage – does suggest to us high value in the extra capability that CSIRO was able to bring. This value may have been further enhanced by the ability CSIRO offered to provide leadership to the project in a way that could deliver the modelling and advice within the tight timelines. As stressed above, the opportunity value of even modestly earlier access to better information could be very high, given the speed with which major infrastructure and wider investment decisions are being made.

I.6 Costs

In one sense, the Sustainable Yields Project came at negative cost to CSIRO – the work was done under a commercial contract negotiated with COAG and should have been cash flow positive. The budget of $12m is assumed to cover, or at least approximate, the opportunity cost of the CSIRO resources used, plus the cost of outgoings.

Of course, the work was only possible because of the ability to draw on a long legacy of investment in building the understanding of these systems, and the work done early in the life of the Flagship, and the ability to tap into capabilities external to CSIRO as well as across CSIRO (as set out in the next section). Included in these capabilities was major investment over many years by all directly affected jurisdictions – in understanding at least parts of the Basin hydrology, in assessing sustainable yields and testing these assumptions through active resource management.

In aggregate these costs would be very substantial, but arose in large part as normal costs of doing business in these river and groundwater systems – with these costs being justified at the time by the value of these systems in system operation. Both costs and credit need to be shared widely – but we have concluded that CSIRO's was able to shape the study in a way likely to have added significant value in a range of ways.

Similarly, CSIRO's legacy drew strongly from important land and water assessment work over many years. These costs were essentially sunk by the time the study was done, but it is unlikely that the earlier work was not reflected in substantially better planning and resource use over many years in advance of the study.

I.7 Linkages across CSIRO

The WfHC Flagship, and the work done on Murray-Darling Basin modelling, have drawn on a range of pre-existing and capabilities within CSIRO and on capabilities that are evolving elsewhere in CSIRO in parallel with the work in the Flagship.

Substantial inputs to the work have come from:

- Land and Water
- Sustainable Ecosystems
- Marine and Atmospheric Research
- Mathematical and Information Sciences
- ICT centre
- Entomology

J Resistant Starch Grains

J.1 Key points

- Grains with high levels of resistant starch have been shown to have preventative health benefits when eaten in sufficient quantities by people who previously had a low fibre diet.
- CSIRO became interested in researching the nutritional properties of grains while most other researchers were still only focusing on productivity benefits.
  - CSIRO appears to be well ahead of other researchers in the area of nutritional grains research.
- CSIRO has patented a form of Barley which has high levels of resistant starch. This grain is now in commercial production.
- CSIRO has used the technology and lessons learned with BARLEYmax™ to develop a high amylose wheat, which is expected to be commercialised by 2013.
- The benefits created by investing in these two grain varieties have been conservatively estimated to be as high as $554 million. The major driver of the estimated benefit arises from the savings in years of Australian's life lost to disease and savings of years of Australian lives lived with disease.
  - However, with even more very conservative assumptions for take up, and the value of a statistical life year and a discount rate of 7 per cent the measured benefits fall to around $98 million, which is still significantly higher than the real 2010 dollar cost of the investment by CSIRO and its partners.
- These estimates do not factor in a range of values and options created by the research and commercialisation including:
  - Any premium on the processed food produced using the two grains.
  - The option value created by opening up the potential for introducing the capability and knowledge CSIRO has developed to produce preventative health benefits in other grains and crops, with the likely next contender being rice.
  - The option which has been created to develop a new export market for BARLEYmax™ and HA wheat.
  - The stream of royalties and license fees associated with exports and/or the sale of the patent to overseas grain growers and food producers.

J.2 Introduction

CSIRO has patented a form of Barley, known as BARLEYmax™, which has enhanced preventative health nutritional benefits, arising in part from the high levels of resistant starch in the grain.[48]

Barley is a relatively less complex grain on which to undertake research than wheat. However, CSIRO's research on the barley model has allowed it to use the knowledge learned from its BARLEYmax™ work to push ahead similar research on wheat. This wheat research is now showing strong results and is expected to result a High Amylose[49] (HA) wheat variety with similar preventative health benefits to BARLEYmax™ being brought onto the market around 2013.

CSIRO's decision to focus on nutritional rather than only productivity related grain research appears to have put it at the "head of the pack" – potentially 5 years ahead of other similar research globally. It appears that at this stage no other organisation or business has been able to develop barley or wheat with the high preventative health properties identified in the CSIRO grains.

J.3 Australian grain production

The Australian grains sector has four distinct groups of grain:

- wheat such as bread wheats and durum wheat;
- coarse grains such as barley, sorghum, oats, triticale and maize;
- oilseeds such as canola, cottonseed, sunflower seeds and soybeans; and
- pulses such as lupins and peas.

Wheat is by far the largest and most valuable of these grain groups and the food products made from wheat could be considered as staples in the Australian diet. ABARE has forecast that the 2009-10 wheat crop will be in the order of 21,656 kt. Of this Australian flourmills traditionally use about 2.5 million tonnes of wheat per year which is used to produce flour for human consumption as well as producing products destined for industrial uses.

ABARE has forecast that the 2009-10 barley crop will be in the order of 8,048 kt. The majority of barley produced in Australia is exported. The remainder is used domestically for feeding animals or for malting and brewing, only a small amount of barley is currently used directly for human food.

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48 Resistant starch is not digested in the small intestine and therefore adds a form of fibre to the human diet.

49 Amylose is a form of resistant starch.

Table J1 **Australian wheat and Barley production (Wheat product kilo tonnes)**

	Wheat	Barley
1998-99	21465	5987
1999-00	24757	5031
2000-01	22106	6742
2001-02	24298	8280
2002-03	10132	3864
2003-04	26129	10382
2004-05	21904	7740
2005-06	25151	9482
2006-07	10822	4257
2007-08	13569	7159
2008-09(s)	20938	7668
2009-10 (f)	21656	8048

Data source: ABARE

J.4 Health issues

Australia's National Health Priority Areas are cardiovascular health, cancer control, injury prevention and control, mental health, Diabetes mellitus (Type II diabetes accounts for accounts for 85 to 90 per cent of all people with diabetes), asthma, arthritis and musculoskeletal conditions and obesity.

In 2003 (most recent data) more than 2.63 million years of 'healthy' life (i.e. disability-adjusted life years or DALYs) were lost due to the burden of disease and injury in Australia. Of this total burden:

- cancers accounted for 19 per cent
  - the leading specific causes of the cancer burden were lung, colorectal and breast cancers
- cardiovascular disease accounted for 18 per cent
  - the leading specific causes of cardiovascular disease were Ischaemic (coronary) heart disease, stroke, and peripheral vascular disease.

Table J2 **The burden of selected diseases**

	DALYs			YLL (mortality burden)		YLD (non-fatal burden)	
	Total	Male	Female	Male	Female	Male	Female
Colorectal cancer	63,605	34,643	28,962	27,997	23,735	6,646	5,227
Type II diabetes	132,940	71,176	61,763	15,273	11,751	55,903	50,012
Ischaemic heart disease	263,497	151,107	112,390	128,991	89,152	22,116	23,238
Stroke	118,462	53,296	65,166	36,152	48,548	17,144	16,619
All disease	2,447,719	1,235,110	1,212,609				
All disease and injury	2,632,769	1,364,614	1,268,155				

Data source: Begg S, Vos T, Barker B, Stevenson C, Stanley L, Lopez AD, 2007, The Burden of Disease and Injury in Australia, 2003, PHE 82. Canberra: AIHW

J.4.1 Health benefits of CSIRO's barley and wheat grains

CSIRO's research has shown that the new non-GM BARLEYmax ™ grain contains twice the dietary fibre of regular grains, four times the resistant starch and has a low GI index. The HA Wheat also has similar nutritional properties.

Research has demonstrated a strong link between high fibre diets and improved health outcomes, examples of this research are shown in the following table.

Table J3 **Health benefits of adding high fibre to a low fibre diet**

Health Benefit	Level of certainty of health benefit	Level of health benefit (risk reduction) established	Research
Cardiovascular diseases	High	10 to 40 per cent risk	(Dwyer, 1980) (Len Marquart, 2007)
Type II diabetes	High	Up to 26 per cent	(Len Marquart, 2007)
Colorectal cancer	Moderate to High	Up to 40 per cent	(Bingham, 2003)

Through an extensive program of experimental studies, including a number of human trials, it has been shown that a range of foods produced with BARLEYmax™ as their key ingredient have a low glycemic index and also produce positive changes in a range of biomarkers of bowel health in rats.

Processed products using BARLEYmax™ and/or the HA wheat if accepted by consumers as part of their regular diets could have preventative health benefits for a number of chronic diseases (colorectal cancer, heart disease and stroke, Type II diabetes and related to this obesity) which have a high prevalence (and related to this high social and health costs) in Australia and most other developed countries.

Thus CSIRO's research which has produced the BARLEYmax™ and HA wheat grains falls within the Government's National Health Priority Areas. The research is now on the commercialisation pathway and shows significant potential for improving Australians cardiovascular health, reducing the incidence of colorectal cancer and Type II diabetes.

J.5 Research Origins and future research

CSIRO has a long history of interest in and contribution to barley and wheat research. This work originated in CSIRO's Plant Industry Division in the 1990s. Around this time CSIRO also took a strong research interest in developing grains with improved nutritional value. At that stage most grain research outside of CSIRO focused on productivity related issues rather than grain quality. This work required a multi-disciplinary, cross divisional team.

CSIRO's nutritional grains work originally commenced in wheat, which reflects its importance in Australian agricultural grain production and its attributes as a staple part of the Australian diet. However, the wheat grain is complex and the research progress was relatively slow. A decision was made to also examine the possibility of using a "simpler" grain such as barley to push ahead the nutritional grain research.

In the 1990s, CSIRO researchers had put together a collection of new non-GM barley grains and a decision was taken to assess whether any of the grains in this collection had the potential to improve health by delivering high levels of resistant starch and other dietary fibre components. This work led to the identification of the barley mutant gene which has subsequently been developed in a barley variety known as BARLEYmax™.

This work, which had commenced in the Division, was eventually moved into the Food Future Flagship, where the expertise of scientists from the Plant Industry and Food and Nutritional Sciences divisions was utilised to produce BARLEYmax™ and the new HA wheat variety.

It is understood that CSIRO plans to use the capability developed in its BARLEYmax™ and HA wheat research to develop preventative health nutritional benefits in other grains, in particular rice.

J.5.1 Research cost

The direct research cost associated with undertaking this research in nominal and 2010 dollars is shown in the following table. The time frame for the research expenditures are shown in the Figure. It can be seen in the case of BARLEYmax that the majority of the cost of has been borne by CSIRO.

However, in the case of the wheat research the bulk of the funding has been provided by the GRDC and Limagrain Céréales Ingrédients (LCI).

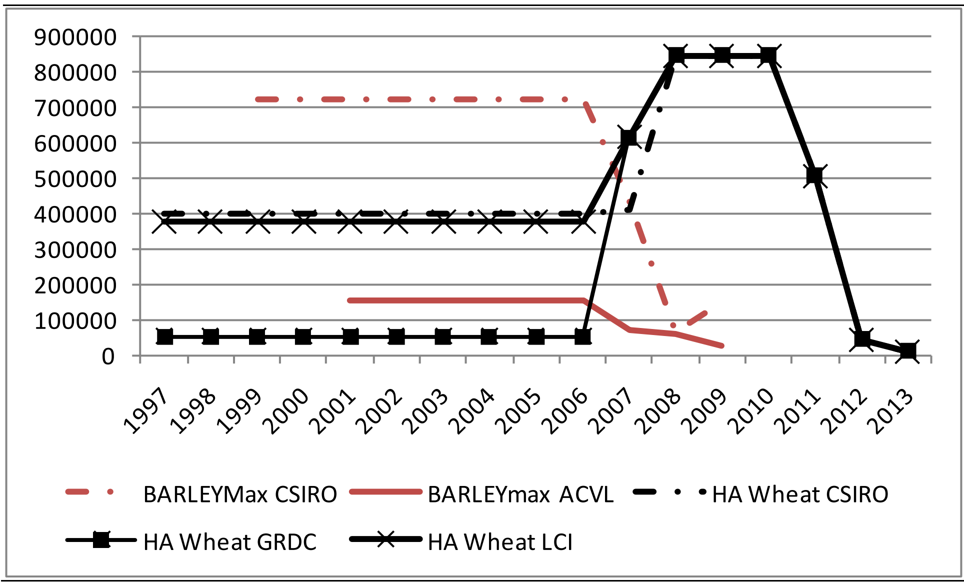
Table J4 **Investment in BARLEYmax and HA wheat R&D**

Nominal $m	Total	CSIRO	Partners
BARLEYmax	7.496	6.434	1.062
HA Wheat	17.588	6.946	10.642
Total	25.084	13.380	11.704
2010 real $m			
BARLEYmax	15.77	13.62	2.15
HA Wheat	36.16	14.55	21.61
Total	51.93	28.17	23.76

Note: ACIL Tasman has estimated that in addition to the actual funding to date for the HA wheat a further $0.985 million of CSIRO funding and an addition $1.97 million of partner funding would be required. This estimate is based on the funding profile for the last years of the BARLEYmax R&D and commercialisation.
A 4 per cent real interest rate and a 7 per cent discount rate have been used to estimate the real NPV 2010 cost of the stream of investment

Data source: CSIRO and ACIL Tasman estimates

Figure J1 **Annual investment in BARLEYmax and HA wheat R&D (nominal dollars)**



Note: Over the period from 2008 to date CSIRO, GRDC and LCI have equally contributed to the HA wheat research. Estimated expenditure on the HA wheat R&D for the period from July 2010 to 2013 have been estimated by ACIL Tasman.

Data source: CSIRO and ACIL Tasman estimates

J.6 Commercialisation

J.6.1 The commercialisation strategy

CSIRO's commercialisation strategy for both grains involves a strategy which moves the two grains (and the products produced from the grains) from being a commodity, which competes in a market which produces only "normal profits", to a differentiated product, which has the potential to generate much higher returns to the licensed producers and food manufacturers and the investors in the research. This strategy largely reflects the Food Futures Flagships goals to improve the profitability and competitiveness of Australian agriculture.

The introduction of a new grain to the market involves risks and uncertainties, thus keeping a tight grip on the two technologies IP, at least in the short term, makes good sense. This is because the new grain is largely untested in terms of grower acceptance and consumer taste preferences. Thus the commercialisation approach could be seen as a means of "proving up" the technology.

However, in the longer term the commercialisation strategy is effectively 'rationing' the number of products that can be produced with these new grains. This rationing runs the risk of reducing the preventative health benefits of BARLEYmax™ and HA wheat to a relatively small number of Australians. Further because price premiums are expected, the strategy also runs the risk of encouraging other research groups to hasten their work to bring a substitute grain with preventative health characteristics to the market.

J.6.2 Commercialisation of the new grains

In 2001 CSIRO entered into an agreement with Australian Capital Ventures Pty Ltd (ACVL) to research and breed new BARLEYmax™ varieties and work with food processors to create new BARLEYmax products.

In 2008 CSIRO and ACVL entered into a licensing arrangement with Austgrains Pty Ltd for large scale commercial BARLEYmax™ crop production. The first commercial crop was grown in 2009.

CSIRO and ACVL have also entered into a license agreement with Popina Food Services, a Dandenong based Victorian food producer, which allows the company to use BARLEYmax™ in its breakfast cereals. In August 2009 Popina put the first two BARLEYmax™ products on supermarket shelves under the Goodness Superfoods brand. These breakfast cereals are marketed as Digestive 1st and Protein 1st. A third cereal is expected to be marketed in late 2010 once the next crop is harvested.

It is understood that there was initially a good uptake of these two BARLEYmax™ products. However, the failure of much of the first commercial BARLEYmax™ 2009 crop, has resulted in the two Goodness Superfoods brands containing BARLEYmax™ being rationed to supermarkets. However, this rationing situation is expected to be reversed with the harvesting of the next crop in November 2010. And it is understood that Popina Food Services is willing to purchase all the BARLEYmax™ grain that is expected to be commercially available in November 2010.

It is understood that CSIRO is currently in negotiations with several other companies. However, at this stage no detail is available on the expected uses of the BARLEYmax™ product or on its international reach.

CSIRO is understood to be experiencing strong international interest in BARLEYmax™.

As discussed above, CSIRO has also identified a wheat gene which has excellent preventative health properties. To bring this grain to the market a spin-out company Arista Cereal Technologies Pty Ltd has been formed. This HA wheat grain is expected to be available in commercial quantities in 2013.

J.6.3 Current and expected future production

There are significant seed availability and logistics issues (and added to this commercial risk) associated with ramping up production of a new grain, such as BARLEYmax™.

It was originally intended that some 2,000 tonnes of BARLEYmax™ would be produced for commercial sale in the first crop. However, the drought and related high temperatures in November 2009 saw most of the crop fail and only 650 tonnes were available for commercial sale. The 2010 crop, which is to be harvested in around November, is expected to produce 5,000 tonnes of grain. This expected production equates to 0.062 per cent of the forecast production for 2009-10.

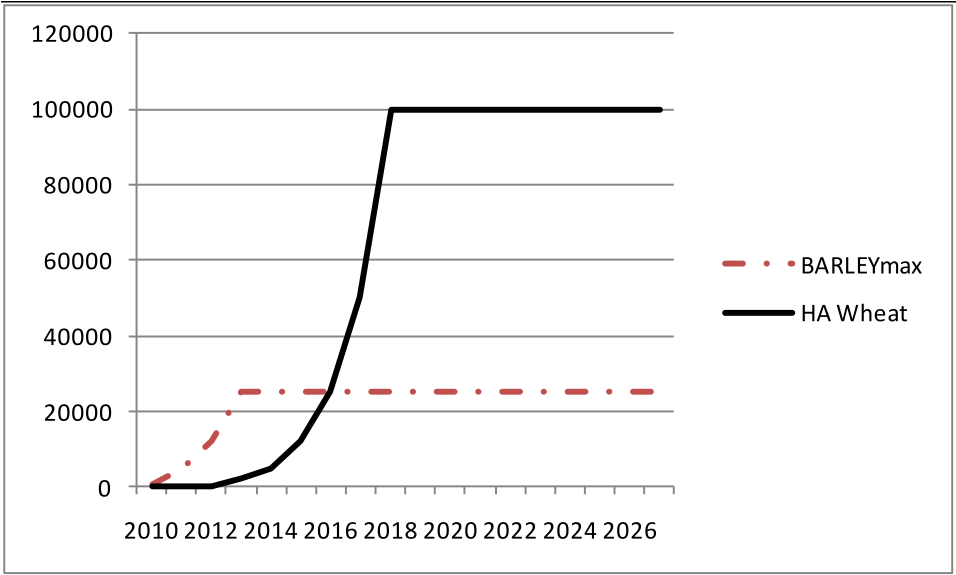
Under the CSIRO BARLEYmax™ commercialisation model the original projections on market demand for Australia were around the 10,000 tonne mark. However, after the early testing of the market with the breakfast cereal in 2009 they have increased the target production to around 25,000 tonnes, which equates to around 0.3 per cent of the forecast production for 2009-10.

CSIRO expects that the demand for HA wheat in the Australian market is around 100,000 Tonnes. This expected production equates to only 0.46 per cent of the forecast production for 2009-10. CSIRO has advised ACIL Tasman that it expects that this wheat variety, under its commercialisation model, would sell for around $500 per tonne. This would imply that the grain achieves a premium in the order of $150 to $200 (or more) per tonne.

However, the two grains have a lower yield than some other available barley and wheat grains. In addition there would be extra stewardship costs associated with ensuring the grain attributes are maintained and tracked from seed planting through to harvesting and through to delivery at the food processor end.

The BARLEYmax™ and HA wheat production levels assumed for this analysis are shown in the following figure.

Figure J2 **Assumed Australian Production of BARLEYmax and AH wheat (tonnes)**



Data source: CSIRO and ACIL Tasman assumptions

J.7 Assessing impact and value

There are a number of value propositions for the successful introduction of BARLEYmax™ and HA wheat to the market.

J.7.1 Grower premiums

The first of the value propositions is the potential for Australian farmers and licensed food producers to achieve a premium price for growing and processing these new differentiated strains of barley and wheat.

The premium on the grain that would be achieved will be dependent on the market circumstances at the time the grain becomes commercial. However, as noted above, CSIRO is expecting that the grower premium on the new HA Wheat grain will be substantial being in the order of $150 to $200 per tonne.

The premium on the processed food produced using the two grains would be dependent on how much the food product can be differentiated from competing foods. However, it could be expected that any price premium achieved for both the grain and the processed foods produced using the grain would reduce as overtime as other grains with similar nutritional properties become more common.

For this analysis we have elected to be conservative and have assumed that the grower price premium (net of additional costs and yield differentials) on the grains could be as high as $50 per tonne, which is more modest than might be estimated by CSIRO. Food processor price premiums have not been quantified as benefits in the analysis, though it is recognised that these benefits are real and may be significant, particularly over the short term.

J.7.2 Royalties and license fees

Another benefit, which has been included in the quantitative analysis, is that CSIRO and its partners are and will continue for some time to enjoy royalties and license fees through the implementation of the commercialisation strategy. However, once again the length of time that these returns on investment can be enjoyed is dependent on the timing of alternatives coming onto the market and the success of the commercialisation strategy.

As the royalty and license fees are commercial in confidence, for this analysis assumptions have been made regarding the likely return to CSIRO and its partners from Australian royalties and license fees. We have not included in the analysis any future royalties or license fees arising from CSIRO selling the BARLEYmax™ and HA wheat technology to overseas growers or producers.

J.7.3 Option value

CSIRO by undertaking this research has also created a valuable option for introducing the capability and knowledge it has developed into other grains and crops. As noted previously, CSIRO is planning on using a similar approach to create a high amylose rice variety. However, it is feasible that the technology could potentially be also applied to other crops at some point in the future. This option value is likely to be considerable, however, for this analysis we have not attempted to quantify the option value that has been created.

CSIRO's research has also created an option for Australian grain producers to develop a new export market for BARLEYmax™ and HA wheat. A further stream of royalties and license fees could be associated with exercising this option.

In addition the investment in research has also created an option for CSIRO to generate a stream of royalties and license fees (for CSIRO and its partners) should it be successful in negotiating the sale or license of BARLEYmax™ and/or HA wheat to overseas growers and/or food producers. Once again the value of this option has not been estimated in this analysis.

J.7.4 Preventative health benefits

Another major potential value driver from the successful uptake of these grains arises from the preventative health benefits for the Australian community. This is because reducing rates of colon cancer, heart disease and stroke and Type II diabetes in the Australian community could offer considerable benefits in terms of lives saved and life years living without disease.

Disease prevention also creates the potential for savings in the health system. It is these preventative health benefits which are an important focus of the valuation and impact proposition discussed below.

J.8 The counterfactual

In thinking about the preventative health values and impacts of these new grains it is important to consider the counterfactual (no CSIRO) situation. It is an unlikely proposition that in the absence of CSIRO that some other research would not at some time in the future find genes in other grain (including barley or wheat) varieties which have similar grower premium attributes and similar preventative health advantages to BARLEYmax ™ and HA wheat. After discussions with CSIRO scientists it would seem that CSIRO's multidisciplinary approach and its interest in the 1990s to research grains nutritional quality and not just grain productivity has put CSIRO in a position where it has a first mover advantage of around five or six years. [50]

For this current analysis we have assumed that in the absence of CSIRO's research a grain and processed product with similar preventative health attributes to quality to BARLEYmax ™ and HA wheat would come on the market five years after BARLEYmax ™ and HA wheat. It is also assumed that these alternatives would take a similar time to BARLEYmax™ and HA wheat to ramp up production. Thus, as the substitute grains come to the market the preventative health benefits of BARLEYmax™ and HA wheat decline and eventually fall to zero, compared to the counterfactual.

[50] We also note that there may be other future technological developments, or changes in taste as well as other policy initiatives, such as education programs, which could lead to a change in Australians diets and lead to similar preventative health benefits. Thus we think that the assumed five to six year window of opportunity for CSIRO's grains to create health benefit value seems appropriate.

J.9 Assumptions

J.9.1 Valuing life and its quality

A key to the assessment of benefit has been the estimation of how quality of life changes as a result of prevention of disease and importantly how this change in quality is valued. We have used two measures in combination to assess the impact and value of changes. These are:

- DALYs (disability adjusted life years) which are used to estimate the burden of disease associated with colon cancer, heart disease and stroke and Type II diabetes. The estimates used are for the year 2003, the latest available data (see Table J2). A DALY is made up of two components:
  - "years of life lost" (YLL)
  - "years of life with disease" (YLD)
- The value of a statistical life year. The Office of Best Practice Regulation Review after reviewing the economic literature has recommended that a credible estimate of the value of statistical life for use in cost benefit analysis where lives are saved or the risk of disability and injury is prevented or reduced is $3.5 million and the value of statistical life year is $151,000 ($2007).[51] In 2010 dollars the value of statistical life year is just under $164,000.

When estimating the savings of years of life with disease we have applied a disability weight to the value of statistical life year. The disability weights used are averages for the relevant disease which are based on disability weights for disease and injury that have been published by Australian Institute of Health and Welfare. As an example, the diagnosis and initial treatment of colorectal cancer and being in remission both have a disability weight of 0.43. However, the disability weight assigned after curative primary therapy is 0.2. On the other hand if the cancer must be irradically removed, or is disseminated, the weight rises to 0.830.[52] A simple average disability weight for these various instances of living with the disease is 0.47 and this weight has been applied to the value of statistical life for each estimated life year with colorectal cancer which has been saved.

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51 The Office of Best Practice Regulation explains that "The value of statistical life is an estimate of the financial value society places on reducing the average number of deaths by one. A related concept is the *value of statistical life year*, which estimates the value society places on reducing the risk of premature death, expressed in terms of saving a statistical life year." (Office of Best Practice Regulation, 2008)

52 Note that we did not include the disability weight of 0.930 associated with terminal stage colorectal cancer.

J.9.2 Health system cost savings

Disease prevention also creates the potential for savings in the health system. In assessing these benefits we have erred on the conservative side on a number of fronts. Firstly, our review of the literature only identified 1990s and early 2000's estimates of the average life time treatment costs for the four diseases. Instead of indexing these lifetime costs we have assumed they represent current costs.

It is certainly clear that the individuals who are "saved" from these four diseases are likely to impose other costs on the health system as they grow old living without colon cancer, heart disease, stroke or Type II diabetes. There is no guidance in the literature on the likely health system cost savings that would be associated with Australians avoiding the four diseases in question. Thus our second approach to estimating a conservative lower limit on health cost savings has been to only include a proportion (30 per cent) of these average life time treatment costs savings as a real saving to the health system. We recognise that this assumption is arbitrary. However, we also note that the health system costs savings estimated in the analysis are not the major drivers of value created from the outcomes of this research being brought to the market.

J.9.3 Other Assumptions

In undertaking this analysis of impact and value it has been necessary to make a wide range of other assumptions. These assumptions, particularly in relation to health benefits, risk reduction and health system cost savings are deliberately conservative and are listed in the following box.

	Assumption
Real discount rate	7%
VoSLY ($2007) indexed to 2010	$163,943
Disability weight applied to years of life living with CHD saved	0.31
Disability weight applied to years of life with stoke saved	0.48
Disability weight applied to years of life with colorectal cancer saved	0.47
Disability weight applied to years of life with Type II diabetes saved	0.21

Incidence rate	**per 100,000 of population**	
New cases of CHD per year(Australian Institute of Health and Welfare)	248	
New cases of stroke(Australian Institute of Health and Welfare)	161	
New cases colorectal cancer per year(Australian Institute of Health and Welfare)	61	
New cases of Type II diabetes per year (The Garvan Institute)	451	
Mortality rate	**per 100,000 of population**	
CHD	104.6	
Stroke	30.15	
Colorectal cancer	8.97	
Type II	14.85	
Risk reduction from eating 30 grams of the "good" fibre per day		
	Assumed risk reduction	
CHD and stroke benefit (i.e reduction in disease 10% to 40%)		20%
Colorectal cancer up to 40% reduction	30%	
Type 2 diabetes up to 26% reduction	13%	
Market access		
Number of Australians eating sufficient quantities of either grain when HA wheat reaches 100,000 tonnes of Australian production in 2018 (note this estimate is a modelling result and is shown for information)	3.4 million	
Proportion of these Australians which regularly eat 30 grams of fibre to gain health benefits	40%	
Number of cases of disease avoided in 2018 when HA wheat reaches 100,000 tonnes of Australian production		
(note these estimates are modelling results and take into account the counterfactual situation)		
CHD	343	
Stroke	222	
Colorectal cancer	54	
Type 2 diabetes	116	

Health benefit lag	**Number of years lag assumed**
GI control and diabetes risk – 1 to 2 years	2
Heart disease and stroke less than 1 yr	1
Colorectal cancer up to 5 years	5
Average health system lifetime treatment cost	
Ischaemic heart disease	$20,640
Stroke (Australian Institute of Health and Welfare, 1999)	$25,800
Type 2 diabetes(Australian Institute of Health and Welfare, 1999)	$24,970
Colorectal cancer(Australian Institute of Health and Welfare)	$18,246
Lifetime treatment costs <u>*actually*</u> saved to the health system	30%
Royalty and licence revenue	**Estimate**
BARLEYmax Grower Royalty per tonne	$23
HA Wheat Grower Royalty per tonne	$23
BARLEYmax Mfg royalty per tonne used	$5
HA wheat Mfg royalty per tonne used	$5
Grower net of additional cost price premium	$50

Based on these assumptions we have undertaken what might be considered a typical cost benefit analysis which finds that benefits are in excess of $550 million, which exceeds the directly incurred CSIRO and partners research and commercialisation costs by a factor of more than 10 to 1.

Table J5 **Benefits and costs of BARLEYmax™ and HA wheat**

Benefits NPV	
Value of years of life lost “saved”	$434,779,411
Value of years of life with disease “saved”	$61,874,677
Royalties and licence fees	$10,751,910
Grower premium	$19,230,076
Health system cost savings	$28,041,836
Total benefits	**$554,677,909**
Real Cost (2010 dollars)	
CSIRO	$28,167,779
Partners	$23,761,141
Total cost	**$51,928,921**
Benefit cost ratio	**10.7**

Note: The NPV uses a 7 per cent discount rate. Past research and commercialisation expenditures were indexed to 2010 real dollars.
Data source: ACIL Tasman estimates.

It can be seen from Table J5 that the major driver of the benefit arises from the savings in years of life lost and years of life living with disease.

J.9.4 Sensitivities

Given the large number of assumptions used in this analysis a number of sensitivity tests are clearly justified. As the major driver of the benefits estimated in the value of a statistical life year we have undertaken sensitivity where the value of a statistical life year is only 50 per cent of the value used in the results reported above. The results of this sensitivity are reported in the following table. The table also reports the results of two sensitivities around the proportion (30 per cent and 10 per cent) of Australians who have access to processed foods produced using the grains and are actually eating the grain in sufficient quantities to obtain the health benefits discussed.[53] Sensitivity analysis results are also reported for changes in the real discount rate assumed. It can be seen that in all cases the benefits remain substantial.

Table J6 **Sensitivity analysis**

	50% of assumed VoSL	Proportion of Aust'ns with access & eating grain in required quantity decreased from assumed 40% to 30%	Proportion of Aust'ns with access & eating grain in required quantity decreased from 40% to 10%	4% real discount rate	10% real discount rate	50% of assumed VoSL, & only 10% of Aust'ns with access actually eating sufficient quantity and a real discount rate of 7%
Total estimated benefits	306,350,865	422,422,152	160,074,191	660,209,178	469,633,065	97,992,430

Data source: ACIL Tasman estimates.

A sensitivity which combines the 50 per cent value of statistical life sensitivity, the 10 per cent eating sufficient grain sensitivity and the 7 per cent real discount rate assumption was also undertaken and it was found that the benefits of the research remain positive and are significantly more that the real costs of the investment undertaken by CSIRO and its partners.

When considering the overall benefit and value created by this CSIRO work it is also important to recall that the estimates of health system cost savings are *very* conservative and that the grower premium may be considerably higher

53 Recall that the time required to ramp up production plus the commercialisation strategy adopted effectively rations the grain and thus limit the number of Australians who could eat sufficient quantities to obtain the health benefits.

than assumed. Further only some of the benefits identified have been included in the quantitative analysis. Values created but not included in the quantification of value include:

- Any premium on the processed food produced using the two grains.
- The option value created by opening up the potential for introducing the capability and knowledge CSIRO has developed to produce preventative health benefits in other grains and crops, with the likely next contender being rice.
- The option which has been created to develop a new export market for BARLEYmax™ and HA wheat.
- The stream of royalties and license fees associated with exports and/or the sale of the patent to overseas grain growers and food producers.

K Titanium within Light Metals

In this vignette we revisit an earlier assessment of the Light Metals Flagship, and look particularly at how the value of the options in the titanium theme has moved over the last four years. The experience also provides insights into how active management of an options strategy, including abandonment options, is working within CSIRO as resources are redirected over time.

K.1 Context

In its 2006 assessments, ACIL Tasman undertook an assessment of CSIRO's Light Metals Flagship as one of its major case studies. That study included examining in some detail the work then being done in relation to titanium, alumina although extending also to aluminium and magnesium. We have not attempted a comprehensive reassessment here, but developments in the Flagship since the last review do provide strong demonstrators of some of the value drivers now being considered. In particular, this includes:

- evidence of real progress, broadly in line with the expectations and options modelling in 2006, in relation to titanium processes; and
- evidence of active Flagship management, to lower risks, in line with the options principles built into the 2006 review;
  - with willingness to adapt the strategy to changing information – including willingness to withdraw resources from areas that are no longer as promising, or where external developments have lowered the value of the potential

The 2006 examination raised significant questions regarding the public policy case for high levels of Government funding of the work – recognising the strong emphasis on delivering industrial processes of significant attraction to industry.

That said, a range of public good dimensions to the work were recognised – especially in view of the potential of some of the processes to deliver substantially less energy intensive[54] processing options. It was also recognised that the work was directed at value adding to resources where Australia has a competitive advantage in mining – with the possibility of supporting a greater

[54] At the time of the review, formal carbon pricing was not government policy. It now is, but remains to be enacted and is not Opposition policy. The presence of formal price on carbon, broadly reflective of expected costs of emissions, would have the effect of converting these public benefits into substantially private benefits. Reasonable prospects of such arrangements being introduced – through an ETS, carbon tax or even through direct action initiatives – still imply a level of private benefit in the development of these lower energy options.

share of value adding being done within Australia. In relation to alumina it was recognised that work was being done that appears of relatively greater value to Australia, given the character of Australian bauxite reserves, than would generally be true of overseas competitors. In relation to titanium, the technologies in prospect appeared to offer scope for addressing constraints on Australia's competitiveness associated with the labour, energy and capital intensity of the then available processes.

In balance, the report suggested that it would probably be hard to develop a case for CSIRO moving into these areas, with substantial Government funding, *from scratch* – as in establishing and building up the capability and history that had, by 2006, grown out of many years of activity in CSIRO under earlier business models. Given the prominence of the private benefits in prospect and the inherent capacity of a number of the firms in the metals mining and processing sectors to resource R&D, the areas looked a poorer fit for high levels of Government support.

However, the potential for benefits to Australia did appear considerable and CSIRO had a legacy capability appropriate to the research prospects that was highly relevant and that showed considerable promise. In effect, CSIRO could provide access to a range of innovation options as a result of this history, where the cost of the options was essentially already 'sunk'. In these circumstances, it was arguable that there was a solid economic case for ensuring that the potential value of these options was not wasted.

Indeed, modelling of the value of the forward options, inclusive of risk weighting and relative to a reasonably aggressive counterfactual, suggested a conservative value across the two themes of the order of $466 million to be compared to the then relevant Flagship costs of the order of $15 million. The option value split approximately 60:40 between titanium and alumina.

This assessment of value was, at the time, heavily dependent on commitment to the options-based approach to investment – including willingness to abandon investment in themes if the emerging information suggested that this would be cost effective. The modelling included significant prospects for the research not delivering significant value and it was crucial to the assessment of options value that costs be limited in the event that this is the way the work would play out. The modelling therefore incorporated explicit abandonment options, with significant probabilities of these needing to be exercised.

The sunk costs were treated as irrelevant to forward strategy; the accumulated capability, knowledge and commercial linkages were, on the other hand, central to the value of the forward options. The approach taken to assessing the option value was appropriate to the question of the case for continued investment – within an options approach that would be willing to back off the work should the case for continuation drop substantially.

Our concerns regarding the market failure basis for intervention, via Government funding, at the time were greater for alumina than for titanium. Alumina is dominated by large multinational companies. Recognition of the particular relevance of the proposed technologies to Australian ores was important, significantly strengthening the case but leaving residual concerns and forcing a more aggressive counterfactual.

The titanium work appeared more prospective for creating new opportunities for smaller Australian firms, exploiting the promise of reduced labour intensity relative to the current processes to support enhanced Australian competitiveness.

K.2 Recent trends

Since the 2006 review, the balance of effort in the Flagship has been evolving – with substantial reduction in relation to aluminium and alumina in concert with strong indicators of progress, and value creation, in relation to titanium. Based on both the earlier assessments and the now available information, these trends seem sensible – with both processes appearing to support adding value to the CSIRO portfolio through sensible management of the options.

We consider now, in a little more detail, the nature of the progress with titanium production and manufacturing processes.

K.3 Titanium production & fabrication

Titanium is a light metal with strength, weight and corrosion-resistance properties that have made it attractive for substantial use in aircraft manufacturing and where there is a growing demand for uses in automobile manufacture. Titanium ore is also (and predominantly) used as an opacifier in paints – without the need to process to a metal. Only about 5 per cent of mined ores are processed to metal, though the trends in new uses of the metal would seem to favour this figure growing substantially.

The titanium theme is pursuing two main research paths that may combine to trigger significant opportunities for local production of titanium metal from ores and local manufacturing of products using the metal titanium (and titanium alloys), as well as underpinning technology exports. The two research components cover production of titanium metal from (Australian) ores and manufacturing using the metal. These possibilities were clearly recognised from the commencement of the Flagship. The Theme Goal has remained largely unchanged, except that its timeline has been pushed out.

The stated goal is now the "creation of a world-scale (20 kilotonnes per annum) titanium industry, based on continuous processing and integrated with downstream manufacturing, in Australia by 2020." This compares to an earlier target date of 2012 and aligns it with the timeline of the overall Flagship goal. The Flagship has been interpreting this as requiring something of the order of a halving of both metal and product manufacturing costs.

Integration of a scale objective here reflects, in part, the fact that the economics of current titanium production processes are heavily driven by scale or by low labour costs. Japan is the largest producer of titanium sponge, tapping scale economies, while lower labour cost countries of the former Soviet Union collectively account for about 50 per cent of production. Australia faces great difficulties in competing on the basis of labour costs, or in jumping to a scale sufficient to be competitive based on scale economies. The CSIRO approach is to *attack labour and capital costs and the scalability of the process*, drawing especially on its legacy capability in *fluidised bed technology*.

Integration with downstream manufacturing may not be essential for the economics of metal and alloy production. However, were competitive local production of metal and ores to occur, then this would substantially improve the economics of local manufacturing. The opportunities for a synergistic development of technology packages that benefit Australian industry and add to the share of value Australia can gain from its resources has been a clear incentive from the start.

K.3.1 Titanium production – TiRO process

Australia has the world's largest established economic titanium ore reserves – as ilmenite and rutile – and is the largest producer of these ores. Export sales of the two ores in 2008 totalled about $390m[55]. There is no commercial processing of the ores into titanium metal or alloys in Australia. Ore costs account for only about 5% of total costs of manufacturing titanium plate – so the attraction in exploring ways to compete into the post-mining processes are obvious.

CSIRO has been developing the TiRO process for several years. The process is based on continuous reduction of titanium tetrachloride with magnesium, to yield commercial grade titanium powder. The concept has been proven, with the demonstration of a very small scale plant.

A feature of the process is the way it can be configured to produce titanium powder. Powder is an attractive input into production of titanium products –

55 ABARE, Australian Commodity Statistics 2009.

but currently powder production occurs after the production of titanium ingots, adding to costs and energy use. Direct powder production dovetails well with the work being done on titanium manufacturing processes, including non-melt processing to fabricate titanium-based components. This offers further potential to lower the costs of producing titanium from ore while also supporting lower cost manufacturing based on titanium. It also emphasises the synergies between the two main prongs of the CSIRO work – on metal production and product manufacture.

Timing aside, in broad terms since 2006 the TiRO process has been following the 'optimistic' possibilities set out in our earlier assessment. That assessment inferred potential value of the order of $1.3 billion in the options then in place – but risk weighted these, for research, commercialisation and obsolescence risks, to an adjusted, probably conservative, value figure of $107 million. This figure was assessed net of forward CSIRO outlays – with the heavy discounting including a high probability of effectively needing to write off much of the CSIRO contribution. Given these risks, the abandonment options built into the modelling were of great importance – without these, the options would have been assessed as having no value. These risks were not raised critically – they were seen as inherent in the challenge for titanium and risks that needed to be well-managed.

The earlier assessment was predicated on proceeding, given successful proof of concept, to a small scale pilot plant and then, if successful, to a demonstration plant in advance of a decision to proceed to full commercialisation.

In addition to the success of the proof of concept investment, the team has achieved a very significant, and valuable, advance with agreement being reached with a local commercial partner to joint venture the demonstration process. This would bring a substantial capital injection to allow the process to be scaled up to a demonstration level. This level would be intermediate between the earlier proposed small-scale pilot and the proposed demonstration plant. CSIRO now believes that this intermediate scale plant will be large enough to achieve the objectives for the larger demonstration plant, at lower cost.

We have not attempted a comprehensive remodelling of TiRO. However, revisiting the earlier modelling in the light of the subsequent experience supports several conclusions:

- The proof of concept, and successful conclusion of a commercial agreement to allow for development of a demonstration plant suggests a very substantial increase in option value.
  - Substantially increased chances of success, with two of the major uncertainties now eliminated.

- This value increase is offset somewhat by the revised timeline – intensifying the implications of discounting of costs ahead of returns.
- Conversely, development of a strategy that should obviate the need for a larger demonstration facility contributes by lowering forward risks and indeed the real costs of building that plant solely to demonstrate the capability.
- The fact that CSIRO has obtained full engagement of a commercial partner willing to risk millions of dollars adds a level of auditing of the practicality of the concepts. This commercial reality check also adds further to confidence in the underlying value propositions contained in the work.
  - The options have clearly progressed from interesting theory to commercially attractive investment opportunities – though still investment in R&D rather than production, but serious investment in this last major process is needed before moving to production.
  - Our understanding is that the commercial partner is very much motivated by the opportunity to expand into production – as opposed to investing in the research with the main target being the sale of the technology.
- With proof of concept, the likelihood that some form of process of the proposed type, or with comparable or better economics, will emerge before too long is substantially higher – and this seems likely even with reducing CSIRO's engagement in outer years.
  - The prospects for such a process emerging elsewhere continues to support a significant counterfactual. In the earlier modelling, we assumed that there was up to a 50 per cent chance of this happening.
  - The level of interest in the TiRO process does suggest strongly that CSIRO is currently at the leading edge, probably suggesting that the assumed 50 per cent could now be lowered somewhat – which in turn has a significant impact on value.
- This commercialisation outcome certainly underscores potential value in the technology – even if it is commercialised in a country other than Australia.
  - The major risk to successful local commercialisation still rests with the overall economics of the ore produced in Australia being competitively processed here – factoring in the advantages of avoidance of higher weight and bulk exports as well as direct competitiveness in the technology itself. Australia has competitive advantage through its local access to the ores – but whether it can have overall competitive advantage remains to be shown.
  - Recent work adds substantial to confidence in this prospect, but it must still be seen as a substantial risk.

Taking all these factors into account certainly supports the view that the option value has increased substantially since the 2006 review – we would take the view that it has certainty doubled and may well have increased by significantly more. Based on stress testing of the earlier model in the light of the lessons, this suggests robust option value, based on credible movements in the original parameters, is now well in excess of $200m. This reflects value to the Australian economy – both through prospects for commercial returns to CSIRO and through opportunities for competitive industry development.

This value increase needs to be related to the costs incurred – these are discussed across the titanium work as a whole below. It also needs to be recognised that that option value is fundamentally tied into the Flagship, with its capabilities. The joint venture demonstration should allow for substantial transfer of capability, which may change this requirement.

K.3.2 Titanium alloys

The earlier AT assessment concluded that the option value in possibilities for delivering a competitive new process for producing titanium alloys was, conservatively, of the order of $ 168 million. This involves a separate process, again founded in the same underlying skills of CSIRO. The central plank of the strategy is a demonstrated continuous process. The process can be tailored to different alloy compositions, but the major target market is for Ti-6Al-4V, a titanium/aluminium/vanadium alloy in significant demand, commonly denoted Ti 6-4.

Current commercial production of the alloys requires the production of commercial purity titanium followed by alloying involving multiple steps. The CSIRO process directly synthesises the alloy from chloride precursors, thereby offering potential for significant cost reduction. Again, proof of concept has now been completed – including aviation user assessment of product quality.

Progress since 2006 appears to have been closely analogous to that seen with TiRO:

- A Joint Technology Development Agreement has been signed with a major global user of the alloys.
  - This departs from the local company model used with the metal production – but would appear to offer substantially greater flexibility to achieve market penetration.
- A separate license has been signed for Ti 6-4 alloy, with potential for a very high impact move to a single plant capable of producing a wide range of alloys.

- The earlier work specified a high end potential value of the order of $1.5 billion, with about a 20 per cent chance of making it through all the hurdles.
  - Progress with proof of concept and with commercial agreements both suggest that the prospects for successful delivery of a commercial plant have risen significantly, though again the delay will partially offset these effects.
  - The firmer prospects for a multi-alloy production capability probably mean the high end potential value has been pushed up.
  - The prospects for early commercialisation to occur in Australia have probably fallen somewhat – though the benefits in early commercial application being close to the technology developers and to abundant reliable natural resources (aluminium as well as titanium) should have significant attraction.

Overall, we would incline to the view that the value of these alloy options has probably roughly held or risen a little over the period, but the shape has changed in important ways. The chances of achieving the top end value with a commercial plant within Australia are likely to have fallen a little, but that top end value may well now be greater and the risks of needing to exercise the abandonment options have probably fallen a lot. The potential value of royalty streams and equity returns on the technology appear now to be very substantial.

K.3.3 Titanium product shaping

There have been a range of developments in relation to product manufacture that add strength to the prospects as assessed in 2006.

- A Victorian company (Frontline Australasia) has licensed a process to produce seamless pipe from titanium powder, using the cold spray technology.
  - These pipes have attractive properties for specialist applications, including petrochemicals, desalination plants and naval ships.
  - The process is expected to be scaled up as a pilot in the next 12 months, in part supported by a 'climate ready' grant from the Federal Government.
  - A wide range of applications of the process to specialised components supports broader options in this proven capability.
  - The company is firmly established in the specialised engineering area, including strong links into defence and automotive applications.
- CSIRO is the lead agency in the Victorian Direct Manufacturing Technology Centre, that has received $3m in funding from the Victorian Government.

  - The cold spray technology fits strongly into this initiative as a direct manufacturing technology that might be suited to take up by local SMEs operating in a range of specialist fields.
  - 10 SMEs have already committed $1.5m cash and $1.5min-kind resources.
- Continuous production of titanium sheets from powder has also been demonstrated to deliver physical properties comparable to wrought material.
  - Processes are under way to secure the IP.
  - The continuous process would appear capable of replacing multiple steps in current processes, with potential for significant cost savings.
  - As noted earlier, there are also strong synergies with the work being done on direct production of titanium powder from ores.
  - A key challenge will be to develop the market for the product – this will require a shift in culture, but the potential appears great enough to support good prospects – especially if sound commercial arrangements can be agreed.

We did not model these manufacturing opportunities in detail in the last review – so are not able to reassess the numbers in the context of this vignette. However, we have drawn the following conclusions:

- Collectively, the set of applications shows high prospectivity, supported (and tested) by substantial and diverse commercial interest.
- The synergies between these manufacturing capabilities, the metal and alloy production capabilities and the prospects for Australia being competitive in developing new industry appear very high.
- Downside risks have been substantially defrayed by recent development – though capturing a large share of the potential remains challenging.
- Prospects for significant royalty and equity returns to CSIRO would appear high.

Certainly, these prospects add substantially to the overall value of the work in light metals.

K.4 Costs

Total investment in the theme from commencement out to 2012-13 is estimated to be of the order of $90m and is now tracking at about $10-11m annually. Initially investment was almost entirely from CSIRO, but now external funds cover approximately 25 per cent of the costs and this is planned to increase to 35-40% by 2012-13 It is notable that CSIRO has recently entered into commercial agreements that include CSIRO retention of significant equity

– suggesting that the potential has existed to recover rather more, but a judgment that equity represents a better 'deal'.

Significant commitment of funding from commercial partners for demonstration plants could be expected to alter the balance significantly. Any progression to construction of commercial scale facilities would require large external funding, presumably predicated on a sound assessment of prospects and risks.

The 2006 assessment of option value, with a conservative assessment of value of the order of $275 million from TiRO and continuous alloy production alone, was calculated net of estimated CSIRO outlays from 2007 onwards.

L The UltraBattery

The task of reducing carbon emissions to long term sustainable levels is not a simple one. Achieving the necessary reductions in carbon emissions will require major technological shifts and innovations.

The IEA in its 2008 Energy Technology Perspectives report examined how various technologies can assist the world in moving to a carbon constrained economy. The IEA argued that achieving greenhouse gas emissions reductions in the transport sector will prove particularly challenging.

In making this observation, the IEA considered the abatement potential of vehicle hybridisation, but noted that:

> Energy storage is critical to hybridisation. Currently, this is provided by batteries. Batteries are being steadily improved, but even the best today – the lithium-ion batteries used in small electronics and beginning to be introduced for larger applications such as vehicles – suffer from high cost and inadequate performance[56].

The IEA recognised the importance of battery research and development in overcoming these limitations. In this context, research targeted to assist the world to meet the challenges of moving to a carbon constrained economy should be valuable, even if the outcomes from a particular individual research does not bear fruit. In this context ACIL Tasman's earlier 2006 work on the value of CSIRO research considered a valuation framework, which was termed the "irons in the fire".

The "irons in the fire" approach recognises that CSIRO is but one of many research organisations working to solve "big problems" such as GHG mitigation. CSIRO's engagement, even if it is not the most prospective player, can add to the statistical probability that a solution will be found sooner than in its absence.

CSIRO's battery research has borne some fruit; it has developed a hybrid energy storage device known as the UltraBattery. The battery integrates a supercapacitor with a lead-acid battery in a one unit cell.

The UltraBattery has a number of potential applications including:

- hybrid electric road transport vehicles
- energy storage for wind generation
- energy storage for photovoltaic (solar) energy production, particularly in remote access power systems

[56] IEA 2008; report p.441.

- powering off road vehicles such as electric forklifts.

L.1 About the technology

L.1.1 Supercapacitors

Supercapacitors can store a more charge (energy) than conventional capacitors but share a capacitor's ability to release that energy very quickly. This means they are useful for short term, high-energy applications such as when an appliance is switched on or an electric car accelerates.

Box L1 **What is a supercapacitor?**

A supercapacitor stores energy electrostatically by polarizing an electrolyte solution. A supercapacitor can be viewed as two non-reactive porous plates suspended within an electrolyte, with a voltage applied across the plates. The applied potential on the positive electrode plate attracts the negative ions in the electrolyte, while the potential on the negative plate attracts the positive ions.

This effectively creates two layers of capacitive storage, one where the charges are separated at the positive plate, and another at the negative plate. The two oppositely charged electrode plates are attached to current collectors and are kept apart, prevented from causing a short-circuit, by an ionically conductive but electronically insulating separator material.

Source: CSIRO

CSIRO has reported that supercapacitors have many benefits including:

- they can be recharged very quickly (in a matter of seconds)
- when fitted alongside a battery can extend battery life in certain automotive and stationary applications by 'levelling out' high power demands on the battery (load levelling)
- they can be manufactured in any size and shape
- they can be retrofitted onto existing designs
- the devices are generally made from low-toxicity materials.

By contrast, traditional capacitors (which do not have an ionically conductive insulating material between the conductors) have very limited energy storage capacity when compared to supercapacitors and so cannot provide large amounts of charge without significantly increasing the power solution's size and weight.

L.1.2 Combining supercapacitors with traditional lead-acid batteries

Traditional batteries and fuel cells cannot provide the high power required for higher functionality and cannot provide the burst (or pulse) power that is required for modern technologies such as required in hybrid electric vehicles and wireless communication. Further, these energy sources cannot quickly recharge without significantly increasing the power solution's size and weight.

The UltraBattery improves the performance of traditional lead-acid batteries by combining the low-cost and durability of this technology with a supercapacitor. Supercapacitors allow manufacturers to use smaller, lighter and cheaper batteries to achieve the required level of performance, avoiding the need to fit oversize batteries to cope with sudden surges in power.

Prior to the development of the UltraBattery, supercapacitors and lead-acid batteries had been trialled in combination but as separate components. CSIRO was involved in this early research through the ECOmmodore project (see section L.1.3 below). However, in these instances it was necessary to use a series of electronic controls and complex algorithms in order to switch power between the components.

The key innovation of the UltraBattery is merging the two technologies (supercapacitor and lead-acid battery) into a single battery cell, removing the need for these additional electronic controls and multiple energy storage devices. This has a very positive impact on the weight and cost of the battery storage system.

L.1.3 CSIRO research on supercapacitors

CSIRO has been working on energy storage technologies for over 20 years. CSIRO's supercapacitor work originated through a research program in the Energy Technology Group in early 1992 and since that time has involved 34 researchers from seven CSIRO Divisions.

When CSIRO commenced its research on supercapacitors, the limitations of both traditional battery and capacitor technologies were causing problems in advanced applications, forcing some manufacturers to adopt costly, inefficient solutions to meet their products' power needs.

Both battery and capacitor technologies were mature and further research was unlikely to yield dramatic improvements in their capabilities. While fuel cell technologies are not mature they were focused on large-scale power delivery, while small-scale portable fuel cells under development were unable to provide pulsed power. Research on supercapacitors offered great potential to overcome the limitations of traditional energy storage technologies.

In 1997 CSIRO developed and commercialized this research with its research partner, Plessey Ducon Pty Ltd. CSIRO's research resulted in the world's most advanced high power small form factor supercapacitors. The ultra-high performance of the supercapacitors was enabled through the tailored use of nano-structured materials and nano-scale processes developed by CSIRO over a decade.

The partnership developed high-technology supercapacitors to be used in low-emission, fuel-efficient car designs such as the aXcessaustralia LEV[57], and the Holden ECOmmodore.[58] These vehicles used an energy storage and control system developed by CSIRO, which used a combination of a lead-acid battery in parallel with a supercapacitor. This arrangement required the energy and power flow between the supercapacitor and the battery pack to be managed by an electronic controller. While this supercapacitor and battery system was successfully demonstrated in the two demonstration vehicles, there were drawbacks as the system was complicated (requiring a sophisticated algorithm) and was very expensive. This work on hybrid vehicle energy storage formed the beginnings of what is now the UltraBattery technology.

CSIRO's research on the UltraBattery was eventually moved into the Energy Transformed Flagship, bringing together multidisciplinary research capabilities and skills from at least four CSIRO divisions:

- Energy Technology
- Molecular Science
- Manufacturing and Infrastructure Technology
- Textile and Fibre Technology.

The multidisciplinary Flagship team identified that the UltraBattery technology also offered opportunities as becoming a energy storage source for renewable energy such as wind and solar.

The Flagship is currently undertaking trials of the UltraBattery for storage of electricity generated by three 20kW wind turbines and a 20kW photovoltaic array at its Newcastle Energy Centre and at the Hampton wind farm in New South Wales.

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57 The aXcessaustralia car was designed and built by CSIRO with a consortium of more than 80 companies to showcase Australian automotive expertise. See http://www.csiro.au/solutions/aXessaustralia.html

58 The ECOmmodore uses innovations from across CSIRO. The protype was built in partnership with Holden Pty Ltd. See http://www.csiro.au/solutions/ECOmmodore.html

L.1.4 Commercialisation of the UltraBattery

In 2005 CSIRO entered into an UltraBattery commercialisation and distribution agreement with Japan's Furukawa Battery Company for the manufacture and sale of the battery for all uses (Auto, Motive and Stationary) in Japan and Thailand. Furukawa has subsequently collaborated with CSIRO and developed a suite of additional patents. In 2006 CSIRO expanded Furukawa's right to commercialise the technology in NAFA in certain applications.

Furukawa subsequently entered into a sub-license for the US battery manufacturer East Penn to manufacture the battery in the United States. Under this exclusive sub-license agreement East Penn was licensed to manufacture and distribute the UltraBattery to the automotive sector throughout North America, Mexico and Canada.

In 2007 CSIRO created a new spin out company Ecoult Pty Ltd to develop and commercialise stationary battery-based storage solutions. Cleantech Ventures was a venture capital partner in Ecoult.

In May 2010, East Penn acquired 100 per cent of Ecoult Pty Ltd.

Details of any upfront payments (and/or royalties) to be paid to CSIRO under these commericalisation agreements are not publicly available.

L.1.5 US grants to test and manufacture the battery

East Penn's work on the UltraBattery has been given an additional impetus by the United States Government's August 2009 announcement that East Penn would receive a $32.5 million grant. This grant will allow the company to expand its production capacities to test and manufacture the UltraBattery for hybrid automotive applications.

Another US company, Exide Technologies, was also awarded a $34.3 million grant for the testing and production of advanced lead-acid batteries, using lead-carbon electrodes for hybrid applications.

It is understood that testing of the UltraBattery in hybrid cars is going well. Several original equipment manufacturers, including Toyota, Ford and BMW, are currently testing the UltraBattery for potential use in motor vehicle models which could be produced post 2015.

L.1.6 Australian public funding

The UltraBattery technology has been developed through core CSIRO funding in the Energy Transformed Flagship, and with assistance from a range of grant funding partners. The total funding for this development is $7.715 million. The funding breakdown is outlined in Table L1 below.

Table L1 **Australian Funding development of the UltraBattery technology**

Funding source	Funding	Time period
CSIRO – Energy Transformed Flagship only	$4m approx	2004-
Department of Environment and Climate Change (NSW)	$1.425 m	2009
Department of Resources, Energy and Tourism (Commonwealth) – Advanced Electricity Storage Technologies Program	$1.82 m	-
AusIndustry (Commonwealth Government) – Commercialising Emerging Technologies (COMET)	$120,000	-
AusIndustry (Commonwealth Government) – Climate Ready	$345,000	2008-09

Data source: CSIRO personal communication; www.ret.gov.au; www.environment.nsw.gov.au; www.ausindustry.gov.au.

L.2 Benefits of the UltraBattery

L.2.1 Automotive applications

Environmental and energy security concerns have recently led to increasing government regulation of automotive vehicle emissions, and private activity to develop more fuel-efficient vehicles and vehicles that use alternative sources of energy to petroleum.

A range of alternative vehicles require improved energy storage technologies to achieve significantly larger market share. The UltraBattery could support the take-up of:

- 'mild hybrid' vehicles (the most well known of these being the Toyota Prius): these vehicles combine a conventional internal combustion engine (ICE) with significant battery storage and an electric motor. The electric motor uses the battery to meet peak power needs during acceleration and the battery is recharged through the vehicle's braking or using energy from the ICE. The electric motor can propel the vehicle without the assistance of the ICE at low speeds.
- 'micro hybrid' vehicles, also known as 'idle stop' or 'start-stop' vehicles: these vehicles combine an ICE and electric motor, but do not generally use the electric motor for propulsion. The primary function of the electric motor is as a starter motor to allow the ICE to switch off at traffic lights, avoiding fuel use from idling.

However, we have been advised by CSIRO that the UltraBattery technology is too heavy for use in other 'advanced battery' vehicle types, such as:

- plug-in hybrid electric vehicles (PHEVs): these vehicles are similar to mild hybrids but can plug-in to the electricity grid to recharge. In general, PHEVs would have larger battery storage than mild hybrids and use this storage to travel purely on electricity for a greater proportion of the time, effectively substituting petroleum with electricity as the vehicle's energy source.
- pure electric vehicles (EVs): these vehicles differ from the types above by not having an ICE. Their sole energy source is grid-supplied electricity and so they require significant battery storage to allow longer travelling distances between recharging.

Benefits of hybrid-electric and pure electric vehicles

Commercially available mild hybrid cars have been shown to have a similar performance to a comparable conventional combustion engine vehicle but with an overall increase in fuel efficiency, producing lower greenhouse gas emissions and reducing demand for fossil fuels.

Whilst not yet widely available, micro hybrid vehicles also promise improved fuel efficiency whilst maintaining performance.

Some governments have developed policies that seek to reduce petrol use in the transport sector for energy security as well as environmental reasons. These policies tend to emphasise the geo-political and economic effects of relying on a commodity that is largely imported from politically unstable parts of the world and which has few short-term substitutes. Improved fuel efficiency of road transport vehicles can mitigate these energy security concerns.

Limitations of hybrid vehicles

While hybrid cars can have these positive environmental and energy security benefits they are currently more expensive to buy and maintain than conventional combustion engine vehicles. For example, in Australia a hybrid vehicle costs in the order of $40,000, while a similar conventional vehicle costs $31,000[59]. Currently the take up of hybrid vehicles in Australia is very low, which is in part driven by this cost differential.

The nickel/metal-hydride battery technology used in most hybrids is currently costly and much heavier than batteries used in conventional cars. The life of batteries used in hybrid vehicles is also problematic and on disposal they are not easily recycled.

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59 http://www.carshowroom.com.au/ Comparison is of the 5 door hatchback Toyota Corolla Levin ZR (1.8 L engine, 4 speed automatic transmission) with the standard 5 door Toyota Prius (1.8 L engine). Part of the cost differential can be attributed to the continuous variable transmission used in the Prius.

While some observers expect that lithium/ion batteries will take over from nickel/metal-hydride batteries for hybrid vehicle applications due to their better power-to-weight characteristics and longer life. However, the cost of these batteries is likely to remain prohibitive for the next few years, despite predictions of substantial cost reductions.

Benefits of the UltraBattery

Using the UltraBattery potentially addresses the energy storage issues faced by hybrid vehicles. CSIRO testing has shown that:

- the use of a supercapacitor to provide quick charge and discharge capabilities results in an extended battery life when compared to a lead-acid battery under similar conditions
- the UltraBattery is less expensive than batteries used in most hybrid vehicles.

The battery ease of adoption by current battery manufactures is another important consideration.

If the UltraBattery technology is taken up in hybrid vehicles these advantages could result in a fall in price and hence an increase in the take up of these vehicles in Australia and around the world.

In turn, greater take up of hybrid vehicles will support governments' environmental and energy security objectives.

Drivers supporting uptake of the UltraBattery

In April 2009 the European Parliament and Council passed Regulation (EC) No 443/2009 establishing vehicle emissions standards that seek to limit CO_2 emissions from light duty vehicles[60].

This regulation requires manufacturers to ensure that an increasing proportion of their new car sales, on average, meet emissions limits (differentiated according to the mass of the vehicle) or face penalties in proportion to their vehicle sales and the average extent to which their new vehicles exceed the emissions limit.

On April 1 2010 the United States Government announced new standards for the fuel efficiency of new motor vehicles built in the period 2012-16 to be offered for sale in the US. Building on this, on 21 May 2010 US Government regulatory bodies the National Highway Traffic Safety Administration and the Environmental Protection Agency began consultation on a second phase of

60 http://ec.europa.eu/environment/air/transport/co2/co2_home.htm

rule-making, focusing on creating equivalent standards for medium- and heavy-duty trucks and extending standards to light-duty vehicles of models years 2017 and beyond.

These substantial regulatory measures in the two largest automotive markets in the world will drive substantial effort in the search for cost-effective technologies that improve fuel efficiency.

The UltraBattery and like technologies appear well placed to capture a large share of the market opportunity created by these regulations, particularly because micro- and mild-hybrid vehicles (for which the UltraBattery is well suited) do not face the same short-term constraints on the take-up that PHEVs and EVs face, such as the lack of infrastructure for convenient recharging of these vehicles, and perceptions about vehicle range and convenience.

These issues are reflected in several market analyses which suggest that rapid growth in micro and mild-hybrid vehicles is quite likely in the period to 2020, quite apart from any potential growth in the PHEV and EV market segments for which the UltraBattery is not suited.

For example, the Boston Consulting Group's (BCG's) analysis "The Comeback of the Electric Car?" analysed market trends for hybrid and electric vehicles and found significant potential for hybridisation of the fleet by 2020, but only forecast limited penetration of PHEVs and EVs except under its 'acceleration' scenario. The results of BCG's analysis are presented in Table L2 below, and are based on converting the market shares for each technology into total sales assuming BCG's predicted worldwide vehicle market size of 54.5 million sales in 2020 for the 'steady pace' scenario is constant across the other two scenarios.

Table L2 **Worldwide advanced battery vehicle sales in 2020**

Scenario	Hybrid (market share)	Hybrid (sales)	PHEV (market share)	PHEV (sales)	EV (market share)	EV (sales)	Total sales (million)
Slowdown	11%	6.0 m	<1%	<0.55 m	<1%	<0.55 m	54.5
Steady pace	20%	10.9 m	3%	1.6 m	3%	1.6 m	54.5
Acceleration	26%	14.2 m	6%	3.3 m	10%	5.5 m	54.5

Data source: Boston Consulting Group, "The Comeback of the Electric Car?", http://www.bcg.com/documents/file15404.pdf

Importantly, this analysis does not consider likely penetration rates of micro-hybrids, which were classified by BCG as conventional ICE vehicles equipped with start-stop systems.

In a similar vein, a 2008 Deutsche Bank analysis suggested potential 'electrified' vehicle sales of around 23 million by 2020 in Europe and North America alone, of which micro and mild hybrids consist of around 20.6 million. Micro-hybrid sales were around 10.5 million in these markets[61].

However, other observers have predicted faster growth in the micro hybrid sub-sector, suggesting uptake in the order of 20 million vehicles of this type worldwide per year by 2015[62].

Given these varying estimates, an upper- and lower-bound estimate of micro and mild hybrid vehicle penetration, and therefore the potential UltraBattery target market, could range from:

- 10 million sales per year in 2020 as a lower bound, reflecting slow uptake of mild hybrids as suggested by the BCG slowdown scenario, and incremental penetration of micro-hybrids in the order of 4 million vehicles per year
- 20 million sales per year in 2020, broadly reflecting Deutsche Bank's estimate, noting that Deutsche Bank's forecast excludes the Chinese, Japanese and other markets
- 40 million sales per year in 2020 as an upper bound, reflecting bullish micro-hybrid forecasts of 20 million by 2015 and penetration in the order of 30 million sales per year worldwide by 2020. Under this upper-bound scenario, growth in micro-hybrid sales could tend to 'cannibalise' mild hybrid sales, but these are assumed to still total around 10 million sales per year by 2020.

Potential commercial benefits from the UltraBattery

Noting the regulatory drivers discussed above, there appears a strong likelihood that CSIRO will access significant revenue from commercial agreements to license the UltraBattery technology. However, significant uncertainty remains around the rate at which hybridised vehicles will gain market share in developed (or developing) markets, and this uncertainty supports the use of sensitivity analysis to consider the order of magnitude of these benefits.

Focusing only on the North American and European automotive markets, growth in the order of that predicted by BCG or Deutsche Bank would provide substantial royalty revenues to CSIRO under a range of scenarios.

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[61] Deutsche Bank, June 2008, "Electric Cars: Plugged In – Batteries must be included", downloaded from http://www.d-incert.nl/fileadmin/klanten/D-Incert/webroot/Background_documents/DeutscheBank_Electric_Cars_Plugged_In_June2008.pdf

[62] http://industry.bnet.com/auto/10004095/here-come-the-micro-hybrids-low-hanging-fruit-for-fuel-economy/

The potential benefits below ignore, and therefore are additional to, any up-front revenue earned by CSIRO in entering into its licensing agreements, and look only at the potential ongoing revenue available through per-unit royalties. These revenue streams are presented as discounted revenue streams under the following assumptions and sensitivities:

- Assumed 2% royalty stream being available to CSIRO
- Assumed UltraBattery cost of US$50/unit[63]
- Assumed US$/AU$ exchange rate of 0.80
- Scenarios of the potential UltraBattery market of 10 million, 20 million and 40 million light-duty vehicle sales worldwide by 2020, as discussed above
- Assumed straight line growth in sales of all mild and micro hybrid vehicles from around 1 million in 2010 to either 10, 20 or 40 million by 2020
- Scenarios of UltraBattery licensees capturing 10%, 20% or 30% of this market, with first UltraBattery sales occurring in 2015.

The results of these sensitivities are presented in Table L3 below.

Table L3 **Scenario analysis – potential revenue from UltraBattery automotive use royalties**

Scenario	Penetration of advanced battery vehicles (million sales in 2020)	UltraBattery share of advanced battery market (%)	Revenue to 2020 discounted @4%	Revenue to 2020 discounted @7%	Revenue to 2020 discounted @10%
1	10	10	5.0	4.5	4.1
2	10	20	10.0	9.0	8.2
3	10	30	15.0	13.5	12.3
4	20	10	9.9	8.9	8.0
5	20	20	19.7	17.7	16.0
6	20	30	29.6	26.6	24.0
7	40	10	19.5	17.6	15.9
8	40	20	39.1	35.1	31.8
9	40	30	58.6	52.7	47.6

Data source: ACIL Tasman analysis

Due to commercial confidentiality concerns, ACIL Tasman does not have more information about the license payments already paid to CSIRO or the precise royalty arrangements entered into by CSIRO, or market projections of it or its commercial partners.

Nevertheless, these potential royalty streams reflect the fact that the UltraBattery is likely to prove commercial in its present state of development.

[63] CSIRO personal communication: based on assumption of long-term UltraBattery cost of around 1.5 times the cost of a conventional lead-acid battery, presently estimated as US$30 wholesale (e.g. for purchases by car manufacturers).

This analysis supports the view that CSIRO's development of the UltraBattery has provided, and is likely to provide, a significant commercial return to the organisation as technology derived from the UltraBattery achieves market share.

In addition to the commercial benefits that have and are likely to continue to flow to CSIRO from the UltraBattery, there are a range of other advantages of the technology that may benefit society at large, but which may prove difficult to capture commercially.

Reducing greenhouse gas emissions

A key to the UltraBattery's ability to lower GHG emission from road transport will be dependent on how rapidly lower battery costs translate through to lower hybrid vehicle prices. The very fact that there are other batteries (such as the battery being tested by Exide Technologies in the US) that may also prove suitable for use in these low emissions vehicles should put downward pressure on battery prices and in turn lower vehicle prices.

Thus early competition in the battery market is likely to be important as it opens up the possibility of the UltraBattery having some influence over rates of take-up of new hybrid vehicle technologies which could be out of proportion to its achieved sales – with flow through to global GHG outcomes.

The likely value of the reduction in GHG generated by CSIRO through its research in the battery space for hybrid/electric vehicles is plausibly large when account is taken of the social cost of carbon saved. As discussed in Appendix D, the social cost of carbon has been recently estimated to be $US21 per t/$CO_2$. This estimate is accompanied by a 95-percentile estimate of $US64, rising to $US136 dollars by 2050.) Assuming a medium-term AUD/$US exchange rate of 0.8, the 'central estimate' of $US21 in 2010 converts to about AUD27 per t/CO_2 – rising to about AUD $58 per t/$CO_2$ in 2050.

In addition, it should also be recognised that the early development of proven and cost-effective GHG mitigation technologies may reduce political resistance to adopting mitigation targets by reducing the barriers to effective global action that arise because of actual or perceived 'free-riding'.

Non-greenhouse pollutants

Whilst the use of catalytic convertors have greatly reduced the impact of local pollutants from tailpipe emissions in the developed world, the transport sector continues to impose large societal costs in the developing world from non-greenhouse emissions.

These costs primarily take the form of negative health impacts on urban populations, and can be substantial.

Low-cost vehicles that offer reduced tailpipe emissions through improved fuel efficiency may assist developing country efforts to reduce the negative impact of vehicle use on urban populations.

L.2.2 Applications in the stationary energy sector

The UltraBattery technology could also help to address issues associated with the supply-side volatility of some forms of renewable electricity generation.

A standard electricity grid, such as Australia's National Electricity Market grid, must be electrically stable such that energy demand and supply are constantly kept in balance. The intermittency of wind means that the electricity it produces is variable from minute to minute, hour to hour, day to day and across the seasons.

Whilst all forms of electricity generation can vary in output unexpectedly due to technical failures or changes in operating conditions, the challenge of managing the intermittency of wind is a significant barrier to uptake of these technologies.

Presently these issues are managed through a combination of:

- 'frequency control ancillary services' provided by traditional fossil-fuel fired and hydro generation sources that balance out short-term variations in output of all generators (i.e. including both wind and fossil fuel generators) across the system;
- interconnection, which allows power to be transported from where it is available to where it is needed, helping deal with hour to hour and day to day variability in renewable generation;
- 'peaking plant', which can be switched on rapidly to meet short-term spikes in demand or decreases in generation to match supply and demand; and
- non-battery forms of energy storage, particularly storage provided by some hydroelectric generators where water is pumped uphill at times of low demand to be stored for use when demand is high (pumped hydro storage).

Other than for remote area applications, energy storage with batteries is not cost-effective at present. The battery storage solutions currently available use lead-acid battery systems. These systems experience frequent deep discharging and are unable to meet high power demands. These systems are also expensive due to the high initial purchase cost and the relatively short battery life.

Improved storage technology could remove technical and economic barriers that prevent greater uptake of wind and solar generated electricity. Ultimately the success of the research could result in an increase in the uptake of renewable energy generation in Australia and globally and/or lower the cost of reducing greenhouse gas emissions from the stationary energy sector.

Benefits of the UltraBattery technology in stationary applications

It is expected that the discharge and charge power of the UltraBattery will be 50 per cent higher and its cycle-life at least three times longer than that of the conventional lead-acid counterpart currently used for renewable energy storage.

The UltraBattery technology aims to address a number of issues related to renewable energy systems including:

- improving power 'quality' in grid and non-grid connected systems
- supporting grid stability
- load levelling
- remote area power supply
- emergency back up to ensure uninterruptible power supply.

If successful, this storage device would smooth the input voltage of wind and solar energy feed into the grid, which would improve solar and wind generated energy's 'quality', specifically the extent to which its output varies from minute to minute. This would reduce the costs associated with continuously balancing wind output to maintain grid stability, and may allow a higher penetration of wind generation to be installed without breaching operational limitations of the grid

The storage capacity of the battery could also allow renewable energy to be moved from times of lower value (e.g. overnight) to times of higher value (e.g. mornings and evenings), making renewable generation more profitable and supporting higher levels of penetration. However, such applications would require greater total storage capacity than short-term smoothing applications, increasing the size and cost of the storage system.

In both of these cases, the ultimate benefit is realised in the form of higher levels of renewable generation at favourable locations. Overcoming technical or economic constraints that prevent higher usage of wind generation in locations with high quality wind resources, or that reduce the costs of using solar power, would effectively expand the low cost abatement available from these resources, reducing the overall societal cost of achieving abatement targets.

Benefits of use with wind generation

ACIL Tasman understands that a prospective use of the UltraBattery technology is to smooth wind generation on a short-term basis, allow a higher penetration of wind generation by overcoming technical (grid stability) constraints associated with high levels of wind generation at specific locations.

This is particularly advantageous where wind generation in premium wind locations cannot be increased due to technical limitations on grid operation. Where this occurs, an otherwise economic wind resource may not be able to be used, requiring more marginal wind resources or other higher cost abatement options must be used to deliver society's emissions reduction objectives.

Drivers of uptake

Increasing wind generation is being driven by a range of greenhouse gas reduction policies that support renewable generation.

The Australian Government has implemented the expanded national Renewable Energy Target, to drive uptake of renewable generation to 20 per cent of total electricity supply. This policy is widely support significant uptake of wind as a low-cost, mature renewable technology.

Similarly, the European Union announced as part of its 2007 Climate and Energy Package a policy to derive 20 per cent of its energy requirements (including transport and non-electricity stationary energy) by 2020, including mandatory national-level targets. Whilst the uptake of technologies to deliver on this target will extend beyond the electricity generation sector, uptake of wind is likely to feature strongly. The uptake of renewable electricity is also supported by the carbon cost imposed on fossil-fuel generators under the European Union's Emissions Trading Scheme, which has been in operation since 2005.

A range of American Congressional climate change bills have combined 'cap-and-trade' emissions trading mechanisms with direct incentives for renewable electricity. However, no legislation of this kind has been passed by the US Congress. Nevertheless, US wind generation is supported by a 2.1 cent/kWh 'production tax credit'.

The Chinese Government also has a target to achieve 15 per cent of total generation from renewable sources by 2020, which, given the strong rate of growth in demand for electricity in that country, represents a substantial quantity of new renewable generation investment. As in Europe, the US and Australia, wind power is likely to capture a strong share of this growth due to its cost advantages over solar and the maturity of the technology.

In the context of these major economies directly supporting renewable generation on a large scale, there is a clear market opportunity for technologies that address grid stability issues associated with increasing wind penetration.

Potential commercial benefits

The IEA's Energy Technology Perspectives study of 2008 has offered some point estimates of abatement available from wind generation relative to a baseline scenario that form the basis of ACIL Tasman's estimates in this area.

The IEA has estimated the installed capacity, output and abatement (relative to baseline) from wind generation at various points over the period 2007-2050. These IEA data points are set out Table L4 below.

Table L4 **IEA wind generation growth projections**

	Year	Baseline	ACT Map	BLUE Map
Installed capacity (GW)	2007	94	94	94
	2015	≈120	≈400	≈400
	2030	≈350	≈970	≈955
	2050	≈420	1360	>2010

Data source: IEA, Energy Technology Perspectives 2008, p 343-4

This indicates a worldwide roll-out of around 300 GW by 2015, and around 500 GW by 2020.

The greatest uncertainty of the scale of demand for the UltraBattery technology in stationary applications is the extent to which technical grid stability issues are a key constraint on wind growth, and the extent to which the technology will achieve market share in conjunction with this roll-out and/or allow a more rapid rate of deployment of wind generation.

Again, sensitivity analysis will allow an order of magnitude assessment of the potential royalties available to CSIRO from this application.

The potential benefits below ignore, and therefore are additional to, any up-front revenue earned by CSIRO in entering into its licensing agreements, and look only at the potential ongoing revenue available through per-unit royalties. These revenue streams are presented as discounted revenue streams under the following assumptions and sensitivities:

- Assumed 2% royalty stream being available to CSIRO
- Assumed UltraBattery cost of US$300/kWh

- Assume storage requirement of 0.16 kWh/kW of wind generation capacity[64]
- Assumed US$/AU$ exchange rate of 0.80
- Scenarios of the penetration of this technology of 2%, 5%, 10% and 15% of wind turbine installations to 2020, starting in 2015.

The results of these sensitivities are presented in Table L5 below.

Table L5 **Scenario analysis – potential CSIRO royalty revenue from wind applications**

Scenario	Penetration of technology (% of wind capacity installed from 2015)	Revenue to 2020 discounted @4%	Revenue to 2020 discounted @7%	Revenue to 2020 discounted @10%
1	2	4.8	4.4	4.0
2	5	12.0	10.9	9.9
3	10	23.9	21.8	19.9
4	15	35.9	32.6	29.8

Data source: ACIL Tasman analysis

[64] Derived from CSIRO presentation illustrating configuration of Ecoult trial equipment: http://www.ata.org.au/wp-content/uploads/chris-phyland-slides.pdf. Ratio based on use of 4 x 27 kWh battery bank with 660 kW turbine.

M Mapping of undersea mineral deposits

M.1 Background

The Wealth from Oceans Flagship and partners have assembled *The Australian Offshore Mineral Locations Map*.

- coal
- construction aggregate
- copper
- diamonds
- gold
- heavy mineral sand
- manganese nodules and crusts
- phosphorites
- shellsand
- tin
- tungsten.

The map has been developed to be viewed on the Australian Marine Spatial Information System (AMSIS) developed by Geoscience Australia in consultation with CSIRO and marine research institutions.

M.2 Meeting government information policy objectives

This project meets two information policy objectives of the Australian Government. The first relates to releasing public sector information. The Government largely accepted the recommendations of the Government Taskforce, chaired by Nicholas Gruen, that it should, as far as possible, make public sector information available to the community. In particular, the Government accepted recommendation 6.1 which states:

By default Public Sector Information (PSI) should be:

- free
- based on open standards
- easily discoverable
- understandable
- machine-readable
- freely reusable and transformable

The second policy objective, that has been a long term goal of the Australian Government, is the development of national spatial data infrastructure (SDI). While this has had a slow birth, the Australian and New Zealand Land Information Council (ANZLIC) is developing a national SDI at the present time. A component of a national SDI is accessible public data both onshore and offshore.

There are two other CSIRO programs that are key parts of wider processes developing components of what might ultimately become a national SDI. These include AuScope and the Integrated Marine Observing System (IMOS) being funded under the National Collaborative Research Infrastructure (NCRIS) Program. Both are developing interactive portals to provide access to geoscience and marine data respectively. Although we understand that there are no current plans to integrate these data portals with the AMSIS portal, there would be considerable value in doing so. Such a step would provide access by users to comprehensive data on onshore and offshore mineral and marine resources.

It is also not clear at this point in our research, whether or not the locator map for the Offshore Mineral Locations map is machine readable. That is whether the output can be exported into a Geographic Information System (GIS) by other users. This feature would significantly increase the potential value to others who might want to use the data. However subject to this condition, the map goes a long way to meeting Australian Government information policies.

The provision of this data creates options for the Government to use this data for both decision making and policy formation. For industry it provides information that will help them assess and plan offshore minerals projects at some future time. ACIL Tasman discussed the value created by spatial information in its report prepared for the CRC on Spatial Information in 2008 (ACIL Tasman, 2008) and also prepared valuations for the Auscope and IMOS programs.

M.3 Other related work by CSIRO

We understand that other research teams in CSIRO have been undertaking social research into stakeholders' values and concerns related to seafloor exploration and mining. A series of workshops and interviews were held to identify are potential barriers to development.

Early results identified that any future Australian marine mining industry would be highly dependent on an improved knowledge-base underpinning the regulatory regime, to generate open and transparent communications between stakeholders, and improve the understanding of policy and regulatory processes.

The social and policy debate is currently limited by a lack of regional baseline environmental data and rigorously tested models. Much more information is required for Australia to make informed decisions as to whether marine mining should progress. Environmental concerns dominate the wide range of reactions of stakeholders engaged in CSIRO's social study, but also included a need to understand the resource itself, relative costs and benefits, and the current legislative framework.

The results of this work are also informing the design of a test case intended to measure environmental impact of anthropogenic seafloor activity. Using the combined results the research aims to design a risk-based analysis tools for decision-makers in the minerals and marine industry.

M.4 Value of the program as information

The value associated with the Offshore Minerals Resources map lies in the information it provides for improved decision making and consultation between government, NGOs and industry.

The presentation of the minerals resources data in the offshore region within a spatial information system significantly improves the accessibility of the data and the ability to overlay other spatial characteristics of the offshore such as location of marine protected areas, important fisheries and other marine environmental features. This provides the capability for CSIRO and other researchers to undertake analysis that might not otherwise be possible, or might take longer than is desirable, to resolve questions that arise in consideration of potential mining activities in the deep offshore regions of the continental shelf.

The presentation of the information in the map creates considerable value as a tool for making better decisions in future years. Spatially located information with the ability to overlay other information can help analysis eliminate options that are environmentally unacceptable earlier than other wise and allow more timely consideration of the issues for areas where mining might potentially be considered.

M.5 Future economic potential

Knowledge of new sources of marine minerals has developed considerably in recent decades. Commercial exploitation of marine minerals has been limited to deposits originating from mechanical and chemical erosion of rocks on continents and transported to the ocean primarily by rivers. These are found in relatively shallow offshore areas of the territorial sea and the 200-nautical-mile exclusive economic zone. These resources derive partly from land sources and partly from natural processes within and beneath the oceans.

Minerals derived by mechanical erosion from continental rocks are concentrated in placer deposits, which are sorted by water motion (waves, tides, currents) according to the varying density of the constituent minerals. These minerals can contain heavy metallic elements (barium, chromium, gold, iron, rare earth elements, tin, thorium, tungsten, zirconium) and non-metals (diamonds, lime, siliceous sand and gravel).

Of these metals, gold is mined intermittently offshore from Alaska, dependent on price, and tin has been mined at sites off Thailand, Myanmar and Indonesia. A viable diamond-mining industry exists off Namibia and the adjacent coast of South Africa (in water depths to 200 meters, distance to about 100 kilometers), with recovery of 570,000 carats reported for 2001 by the principal producer (De Beers Marine).

Sand and gravel are being mined from beaches and shallow offshore accumulations at many sites around the world for construction material (concrete) and beach restoration.

An area of potential interest is mining of deep seafloor mineral nodules and deposits. Nodule deposits, containing dissolved metals as a result of precipitation of minerals from seawater over very long periods of time, can be found in some deep water sediments. The most commonly known contain copper, nickel or ferromanganese compounds. Deposits of massive sulphides are also found around seafloor hot springs.

There has been interest in exploiting these deep sea minerals resources for some time. However in the past such projects have been uneconomic compared with land based mining. That said, expectation of higher commodity prices has reignited interest in some quarters in deep sea mining.

The prospect of deep sea mining of such resources from the Australian continental shelf is highly speculative. Off-shore mining will tend to have higher costs than on-shore, though these could under some circumstances be offset by higher quality resources. There are likely to be community concerns with seabed mining – possibly exacerbated by recent experience in the Mexican Gulf. These considerations urge caution in assuming great economic value from such characterisation of possibilities. Nonetheless, the potential for very high value resource projects to be enabled or brought forward in time should not be overlooked.

ACIL Tasman has undertaken several studies of the economic value of better characterisation of geology on-shore, given the nature of the market failure risks that arise in management for exploration leases etc. The value can be very high, though the opportunities need to be approached cautiously. The consideration of the 'counterfactual' will be of central importance to this assessment of economic value.

M.6 Summing up

The production of the offshore minerals map creates value in two ways: it is a further step in the creation of national spatial data infrastructure; and it creates value to governments, NGOs and industry in the assessment and potential development of sea bed mining projects in a sustainable way.

Despite the uncertainties associated with potential development of deep-sea mining, the information is likely to lead to better policy for the offshore mining industry and better decisions by both government and industry.

Also, ACIL Tasman has not at this stage in the research established whether the map is fully machine readable and able to be incorporated into other GIS systems. This feature would greatly enhance its value as a spatial data source and as an input to exploration models. This issue will be discussed with the Division in the course of assessment.

Nevertheless, better information provided by the offshore mineral locations map improves the prospect that options to realise future economic value from offshore mining are not prematurely extinguished because the information that collected by government agencies is not easily accessible.

N Biochar

N.1 Background

Biochar is a type of charcoal which results from the thermal treatment of natural organic materials in an anaerobic environment – pyrolysis. Biochar is a more stable form of carbon than the feed stock used. However, this stability and other characteristics of biochar are influenced by both the type of feedstock used and the temperature it is subjected to.

Biochar may be an efficient way of sequestering carbon in soils used for some types of agricultural production. Depending on the feedstock and temperature of the pyrolysis some biochar may have agronomic benefits under certain crop and pasture conditions. Indeed, there are indications that biochar could be a cost effective soil improver in some agricultural settings, even before attaching value to any carbon capture. More broadly though, the joint benefits agronomic and carbon capture potential are driving current interest in the technology.

Biochar has received considerable attention in the recent GHG policy debates. Views about biochar's potential contribution to national GHG mitigation and adaptation strategies are polarised, ranging from 'silver bullet' to minor contributor status. International land use and land use change (LULUC) accounting rules (Section 3.4 of the Kyoto agreement) effectively preclude the inclusion of carbon capture through biochar applied to soils in national Greenhouse Gas (GHG) accounts, although Australia and a range of other countries have expressed strong opposition to the Section. ACIL Tasman has recently, in work on possible agricultural GHG offset measures, stressed the disincentives for cost effective sequestration that appear to be embodied in the Kyoto agreement provisions and Australia continues to push for change.

A by-product of pyrolysis is synthesis gas (or syngas) which can be used to produce heat or power and that may support greater competitiveness for the technology.

Biochar has also been shown to be able to replace reductants in the production of iron and steel. In 2009 the CSIRO Minerals Down Under Flagship completed full scale trials with the Australian steel industry at OneSteel's Sydney Steel Mill at Rooty Hill. The two strands of work within CSIRO are now being increasingly coordinated, while recognising some differences in the product characteristics between agricultural and steel production.

Biochar manufacture is an established technology. The uncertainties that remain of interest relate mainly to the most cost effective forms of biochar to use (taking into account feedstock and energy costs as well as application benefits) once carbon capture is included as one of the benefits, actual agronomic effects in specific application contexts and the sustainability of carbon captured following applications under various conditions. This last point may prove crucial in having capture through biochar accepted under international agreements – which is likely in turn to have major implications for usage incentives and for the resultant impact of that usage.

N.2 Current status in steel production

The steel trial used about 20 tonnes of biomass from plantations in NSW, converting the biomass into biochar with the desired properties for the recarburisation of steel. The trials were considered a success with the designer biochars demonstrating equivalent performance to conventional material used by the industry in raising the carbon content efficiently in the steel melt.

Further research work is required to determine methods to densify the biochar to reduce the volume for handling, and to better protect the biochar against moisture pick-up after production.

CSIRO estimates that Australia could produce enough biochar for its own steelmaking using mallee as a source of carbon. The process reduces ground salinity (provided the trees are established on ground that would otherwise provide a recharge site for ground water and are sustainably harvested. If forest wastes are used rather than being controlled through burning, bushfire risks and GHG emissions may be reduced [65].

However, if GHG emissions could be significantly reduced if steel maker overseas, particularly in China adopt the technology.

N.3 Current status in agriculture

At present CSIRO has two major agricultural biochar research projects sponsored by GRDC and DAFF. The projects are to be completed by 2011 (GRDC) and 2012 (DAFF).

The capability deployed by CSIRO to the biochar work resides primarily in the Land and Water Division within the Environment group. Dr Evelyn Krull leads the biochar team at CSIRO.

[65] CSIRO Energy White Paper Submission June 2009

Chart N1 **Overview of current CSIRO biochar projects**

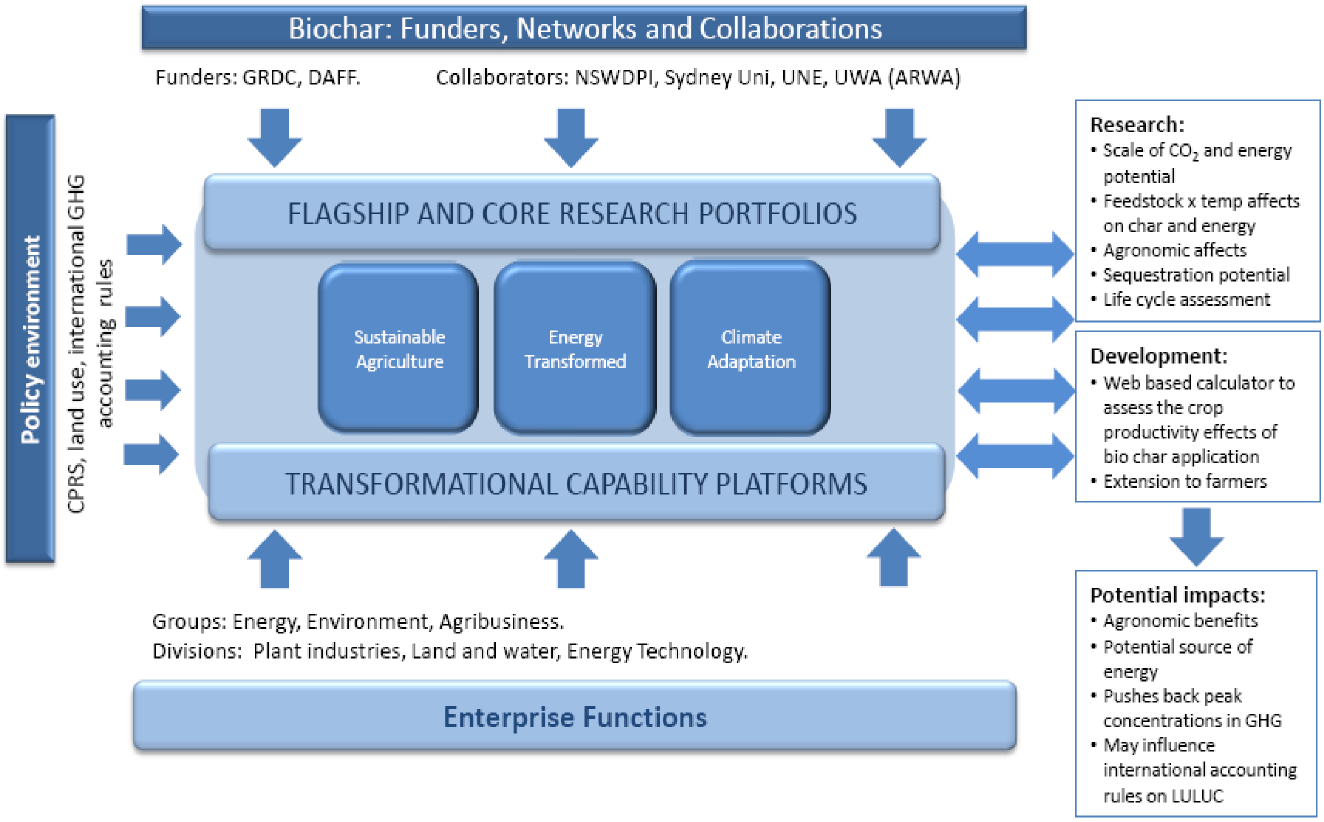


Chart N1 illustrates various aspects and linkages of the biochar projects with CSIRO. The CSIRO contributions to the biochar projects are administered through the Sustainable Agriculture Flagship and it is anticipated that the results of the projects will at least in part be extended through this Flagship. However, the contribution to the Flagship that will be made by the biochar research is yet to be determined.

However, biochar research will also contribute to the Energy Transformed and Climate Adaptation Flagships by:

- Providing research on the syngas by-product as an alternative energy source
- Building greater understanding of water use and water holding capacity and soil carbon

Biochar research is based on historical soils, agronomy and energy capabilities residing in a number of CSIRO groups and divisions.

N.4 Commercialisation

There does not appear to be any immediate plans for commercialisation by CSIRO of the results of the biochar research. Any resulting IP is likely to be shared with GRDC and DAFF as specified in the research projects contracts. The public good benefits of a proven, cost competitive and internationally recognised carbon sequestration technology, that favours Australia's competitive advantage in its land base and agricultural systems, could be very large – though this need not conflict with commercialisation of key elements of IP.

The commercialisation potential s may be substantial, but will be influenced by domestic and international GHG policy. If a price for carbon is established (either through trading or taxation) some forms of biochar may become accredited offset activities.

Biochar may not be as valuable under policies primarily aimed at encouraging adaptation to climate change, unless there are significant agronomic benefits, particularly improving plant water use efficiency from the application of biochar. Some benefits of this form seem likely, but the major opportunity is likely to lie with biochar become a key part of mitigation response – in Australia and internationally.

Substantial work on biochar is being done in Australia and elsewhere and findings are being coordinated internationally – and this has implications for the counterfactual (i.e. in the absence of CSIRO input). However, the key issues in relation to cost effective feed stocks, structure of the biochar process and agronomic and carbon capture value are likely to be strongly site-specific, suggesting potentially high value in a program focused on Australia and Australian soil, water and agronomic systems.

N.5 Research Origins

The current biochar research projects demonstrate the capability maintenance and deployment skills inherent in the way CSIRO operates. The immediate origins of the current biochar research stem from a successful application for $50,000 to the Land and Water Division Opportunity Development Fund by Dr Evelyn Krull. The project was an international literature review of biochar production and application to Australian agricultural soils. This was very much a low cost strategy to acquire some options over a possible area of innovation.

The initial research was commissioned in 2008 and proved timely as during 2009 the CPRS, and agriculture's potential contribution to the national GHG strategy, was extensively debated in the lead up to the Copenhagen meeting. Of particular interest in agriculture's potential contribution to national GHG strategies in Australia were:

- The physical capability, and economic feasibility, of sequestering carbon in Australian soils

- The inherent bias against biochar and other land based sequestration activities in international trading rules specified in the Kyoto agreement

It appears that the CSIRO's work provided an objective, independent assessment of the science of biochar production and its application to Australian agricultural soils, and this influenced the policy debates. This contribution directly led to CSIRO receiving funding from GRDC and DAFF to research biochar in more detail.

N.6 Key benefits emerging from the CSIRO work

The objectives of the combined biochar projects are to:

- Determine the potential amount of biochar and energy that could be produced in Australia
- Formalise the feed stock types and temperature effects on char and energy outputs
- Quantify the benefits of biochar applications to soils with variable chemical and physical attributes
- Assess the sequestration and retention potential of biochar
- Conduct a life cycle assessment of biochar
- Establish a web based decision support tool for famers and others to use to assess the productivity benefits of apply biochar to their soils
- Extend the information to farm business managers through workshops, conference presentations and the publication of articles.

The potential value created by CSIRO's biochar research is likely to be:

9. Sequestration of significant amounts of carbon for various periods leading to permanent delay of peak concentrations of CO_2
10. The application of biochar may reduce total national GHG mitigation costs (subject to the net cost of biochar in a range of applications being below marginal carbon prices - after energy generation and agronomic benefits have be accounted for)
11. Agronomic advantages, such as improved soil structure and water holding capacity, and nutrient management
12. Provide demonstrable benefits of soil carbon sequestration that the Australian Government can use to support its position on international LULUC accounting rules, such as section 3.4 of the Kyoto protocols
13. Support diversification of current efforts focused largely on the use of woody vegetation in the production of biofuels – providing better risk management for these strategies.

N.7 Emerging risks/issues

International and domestic Government GHG policy will have a significant impact on the value of biochar research results. If there is no agreement on changes to international land use, land-use change GHG accounting standards, the value of biochar as a tradable offset is likely to be substantially lower. This does not mean that the Australia Government will not recognise the value of biochar in national accounts, and the new offsets standard certainly allows for recognition of soil capture, but this value will not be translated into a contribution to Australia's international GHG obligations.

In the absence of a change in international accounting standards to allow biochar contributions, they may still be some value in voluntary markets. On the whole, these markets are likely to be lower value as demonstrated by the value of credits traded on the Chicago Climate Exchange (CCX). On this exchange credits have ranged between US$1.00 to US$2.00 per tonne of CO_2e. ACIL Tasman has recently, with support from the NSW and Victorian Governments, flagged some options-based instruments for strengthening incentives for soil-based sequestration even if the international standards have not changed – as long as there are prospects for future change.

If the appetite for mitigation activity diminishes post Copenhagen, and there are signs that this may have been the result in developed countries, biochar may make a contribution to adaptation strategies as well as being a potential credit in voluntary markets. However, biochar's contribution to adaptation is likely to be significantly lower than its value in mitigation policies.

N.8 Why CSIRO is investing in biochar research?

If left to their own devices, private interests are unlikely to invest significantly in broad-based assessment of biochar technologies and in particular life cycle assessment – while Australia continues to reject section 3.4 of the Kyoto Protocol. Rejection of Section 3.4 means Australia (and a number of other countries) cannot include soil-based sequestration activities toward its international obligations. We understand, and support the reasons behind this position, but it does stand as an example of regulatory failure that would seem best addressed via change to the protocols – but that in the meantime suppresses incentives for both research into and use of biochar in agriculture.

The market for carbon credits has to date concentrated its R&D investments on those areas highly prospective for accreditation into the CPRS. Nonetheless, biochar does have particular appeal for Australian agriculture, and for Australia given the nature of its land base. It is notable that the R&D Corporations, created to address market failures in agriculturally relevant R&D, have been one of the major funders to date of CSIRO's work on biochar.

At this stage the most prospective value biochar research may have is to support Australia's case for international rule changes, which private interests are not likely to invest in autonomously. More generally though, the investment could be seen as having highly attractive risk management dimensions for Australia – especially in the scope it may offer to open up access to GHG mitigation strategies that play to Australia's competitive advantage. This of course does not obviate the need to establish that the research makes economic sense, but the potential from a national perspective appears substantial (as do the threats).

O Radioastronomy & the SKA

CSIRO's longstanding involvement in radio astronomy, including its recent large involvement with the Square Kilometre Array telescope (SKA) proposal, and with the Australian Square Kilometre Array Pathfinder telescope (ASKAP) that is being constructed in WA, involve complex value propositions and the commitment of substantial Federal funding over many years.

One reason for selecting CSIRO's engagement in radioastronomy as one of the vignettes in this impact review is its status as an area of fairly 'pure' scientific research. As such, it contrasts sharply with all the other case studies and vignettes considered here – all of which have as a primary motivation and purpose the delivery of more tangible forms of impact and value for the community – including improved competitiveness in the economy, improved protection of environmental assets and reduction in risks posed by such things as climate change.

In the context of a review of CSIRO's impact, the distinction seems one of importance. However, lack of a strong, tangible impact motivation does not necessarily imply low impact or value. Not all values are tangible – governments make substantial investments in 'cultural' assets, often with very little chance of recovering financial costs. In addition though, and of central importance to a balanced assessment of the SKA project, pure research can have significant impact outside the main target of its interest. In some cases this can be serendipitous, in others it can come as a natural by-product of the activities. Radioastronomy within CSIRO has strong examples of both.

Another feature of CSIRO's work in astronomy has been the strong linkages into other areas of CSIRO – drawing on capabilities across CSIRO (as well as across Australia's broader innovation capability) and pushing capabilities in areas – notably in ICT-related areas but extending much more widely – back through CSIRO as opportunities.

Australia's current bid to host the international SKA telescope culminates many years of CSIRO engagement, with other organisations, in the development and application of radio astronomy to the study of the universe. However, the opportunity offered by the SKA is qualitatively and quantitatively different from earlier opportunities in:

- the nature of the international scientific engagement to drive the planning process
- the international competition across sites and technologies to select a package

- the level of expenditure likely to be sourced from outside the hosting country
- the level of complementary investment in broader infrastructure assets – roads, power, broadband etc – expected to be needed.

It is these features that mean the SKA opportunities has prospects for very substantial economic impact for Australia in fairly direct ways – with a real chance that these fairly scriptable impacts could themselves involve substantially greater economic benefits to Australia than Australia's implied contribution to overall project costs.

There are three complementary ways of looking at the major impact and value of radioastronomy, and especially leading edge radio astronomy:

- As a pure science endeavour intended to contribute to our understanding of the universe and of our origins.
- As major, mission-oriented scientific program involving multiple skills tapped from around the world and operating as a large project team, needing to push the limits of a range of current technologies in order to achieve the mission objectives.
  - These technologies include very high speed networking, data transport and analysis; high end engineering, including instrument design, and antennae design and signal processing.
  - The very nature of these technologies suggests significant opportunities for commercial spin-off from radio astronomy work into other sectors dealing with analogous demands.
- A major, high technology engineering construction, support, upgrade and operation project, extending over decades, that will bring with it extensive demand for a range of services, including:
  - Infrastructure delivered into remote areas;
  - Electronics support;
  - Construction services.

We make no attempt to value the pure science involved. In dealing with quite fundamental questions about the nature of our universe and its origins, it is dealing with matters that that many would consider to have high cultural value. The nature of its probing of the universe involves operating in what could be viewed as the largest physics laboratory in the universe, probing the laws of nature as well as the structure of that universe.

Historically, pushing out our understanding of the laws of physics has spawned technology developments of very high value – this potential for 'serendipitous' gains from pure science should not be underrated (See Box O1). The same example illustrates several elements of CSIRO capability to create value out of quality science, coordination across multiple disciplines and an application and commercialization focus.

Box O1 **CSIRO, radioastronomy and wireless networking: value of serendipity & breadth in science**

Wireless networking is now an everyday feature of most computers, many printers and mobile phones, and increasingly of digital radios, televisions and other everyday appliances. A key challenge in developing high speed wireless networking in the 1990s was the problem of dealing with signals bouncing off walls and creating high levels of 'noise' relative to the signal being sought. A number of groups were striving in the 1990s to find a solution – CSIRO succeeded. It did so by tapping into a mix of work done a decade earlier as part of its work on radioastronomy where a precisely analogous problem had been addressed.

CSIRO had already developed a Fast Fourier Transform signal processing capability, integrated into a chip – specifically for the purpose of seeking small 'signatures' of black holes against the very noisy background of radio signals from space. Indeed, the lead scientist in developing the capability, John O'Sullivan, had begun working on the theory for application to yet another variant of the problem in the mid-1970s – in looking for ways to limit atmospheric distortion of optical telescope signals, a technology that is now being built into all the new large optical telescopes. Development of the radio astronomy capability had, in itself, required complex coordination of several capabilities – including across mathematics, radio astronomy, signal processing and very large scale chip design and manufacture where CSIRO had substantial strength in each case. Signal processing and the design of suitable instruments continues to be a core part of radio astronomy ventures and, indeed, of Australia's participation in the SKA project. The technology worked in that it effectively processed the incoming data from a radio telescope in the Netherlands – though at the time failed to detect any black hole signatures.

It was the resultant CSIRO capability and technology in signal processing, using Fast Fourier Transform algorithms built into a chip, that proved so appropriate to the emerging needs for high speed computer networking. This could be viewed as a coincidence, but the fact is that the technologies being pushed to the limit in radioastronomy correlate closely with the exploding demands for high speed communications and processing in the commercial world. Similarly, the antennae array technologies correlate with commercial and defence demands for improved radar detection technologies, the networking of multiple antennae requires very fast wired networking and data capture and processing capabilities etc. There is a difference between blind luck and serendipitous opportunities emerging from one area that is using technologies recognised as being closely linked to those in demand in other areas. Both require some luck – as doers all research – but the latter is likely to support much stronger options over the potential for spin-off technologies. Of course, in both cases you need systems and capability that can spot the opportunities and follow through on translating a possibility into a reality fast enough to gain advantage over competitors.

CSIRO had begun serious exploration of opportunities to commercialise its radio physics capabilities from about 1990. This placed it well to recognise the opportunity, as wireless standards were being developed, and in 1996 established an international patent that was incorporated into the IEEE 802.11a standard that later flowed into the 802.11g and n standards. Parts of the IP were later developed into a commercial chip by Radiata Systems (a CSIRO/Macquarie Univerity spin-off, sold to CISCO Systems in 2001 for about AUD500m) The underlying patents, that remained with CSIRO, were widely disregarded as the technology was installed in billions of devices, but a series of settlements since 2007 has clearly established CSIRO's rights to substantial recovery and forward revenue flow.

It is arguable that this outcome relied strongly not just on the quality and timeliness of the original signal processing work within radio physics, but also on the depth of CSIRO's involved that had it well placed to identify, engage with and respond to the emerging networking opportunity – and the depth to be able to pursue some of the largest firms in the world to assert its rights over the associated IP.

The revenue stream has been substantially earmarked for reinvestment in innovation via the national Science and Industry Endowment Fund.

Having said that, radioastronomy (and astronomy generally) has in recent decades moved strongly into the 'big science project' area – big enough to require (as well as benefit from) international cooperation to share costs and access to very expensive facilities. This is especially true given the almost inherent 'public good' nature of the main products of astronomy projects. The trend has been to siting the facilities in the best location to support the science, and to establish arrangements to share costs and access in ways that reflect capacity to contribute and the value offered, to the overall project objectives, as a result of granting access to groups of scientists.

The SKA proposal is a clear example of this evolution in big science projects. For a country the size of Australia, this general trend suggests some care needs to be taken in choosing where, and on what scale, it is prepared to become involved in 'big science'. If it is to be selective, then it would seem natural to favour involvement in areas where Australia has some competitive advantage. For example, competitive advantage in:

- the siting of and support for facilities
- Australia's capacity to contribute to the design and effective use of the facility
- Australia's ability to leverage advantage from the willingness of other countries to share costs.

ACIL Tasman prepared for CSIRO the original business case to commit to supporting the international SKA project and competing to host the facility. We revisited this work in relation to our support for the consortium (coordinated by CSIRO) that developed the Astronomy bid to the Federal Government for funding under the National Collaborative Research Infrastructure Scheme – that included funding for one of the central planks of Australia's bid for SKA hosting – the Pathfinder radio telescope in WA that was to serve as a demonstrator of substantially Australian-developed technologies to allow the SKA concept to be realised. Both these business cases were based in the same options framework that we are using in the current review.

This vignette builds on and updates that earlier work.

O.1 The proposed SKA project

The capacity of telescopes to probe the universe are liked fundamentally to the number of photons that can be detected – the 'collection area' of the instrument – and to the distance between different parts of that collection area, that influences the capacity to perceive and resolve detail. This has driven the trend to larger collection areas and to networking geographically separated detectors.

A consequence of this trend has been a push into instruments that continuously gather much greater volumes of data from dispersed sites – data that needs to be networked into an accessible database suited to detailed research.

The proposed Square Kilometre Array Telescope would entail the construction of a radio telescope with multiple antennae networked in this way. The proposal is that the aggregation collection area across all antennae be approximately 1 square kilometre – a massive increase over any existing instrument. It is also proposed that the antennae be blocked into approximately 150 stations and spread across a large, continental scale, area – with the distance between the most extreme antennae being of the order of 3,000 kilometers or more. Indeed, the current Australian and New Zealand proposal would have dishes near Perth in Western Australia and in new Zealand. It is this spread that would a offer a massive increase in resolution relative to any existing instrument.

The volumes of data that would be collected from such a system would be massive. On the other hand, the depth of information yielded is expected to add greatly to the capacity for scientists to probe the nature and history of the universe and the very nature of matter and energy. In scientific terms, these considerations combine to imply a high cost and high potential value project. However, it goes further: there is still no fully demonstrated technical system that will allow the objectives of the SKA to be achieved. The design pushes beyond currently established capabilities of technology.

Early stages of the project were directed at developing promising technical solutions to these needs – with a wide array of solutions being proposed. Some emphasised 'big engineering' solutions, with complex engineering structures; others, including an approach promoted strongly by Australia, relied heavily on smart antennae technology coupled with pushing out the boundaries of our ICT capabilities to deal with the data volumes, focusing and networking needs.

Crucially, this has meant that the instrument planning processes have required massive innovation in their own right – with international competition to develop the best solution. It is not just the application of the SKA that will advance science – the design of the basic instrument, along with reasonable expectations of future demands for new instruments and capabilities, are themselves leading edge science projects.

In parallel with the technology design processes has been a process directed at determining where the instrument should be located. Initially, a wide range of sites were proposed, including sites in most continents. At the time ACIL

Tasman developed the original business case, there were still five candidate sites. That has since reduced to two:

- an Australian proposal for the antennae to be spread, broadly east-west, across Australia and into New Zealand
- a South African proposal that the antennae be spread, broadly north-south, across South Africa and into some countries to the north.

The project is being driven internationally by a consortium of institutions from 19 countries. The Consortium has set out five areas of inquiry as the key science drivers of the project – seen as areas of both great interest and science/cultural value and as being areas where this type and scale of radio astronomy capability could be expected to make a really big difference. These areas, characterised as key research projects, are[66]:

- **Cradle of life** – this will explore whether there are Earth-like planets around other stars, and whether they host intelligent life, thus helping to answer the eternal question of whether there is life elsewhere in the universe;
- **Probing the Dark Ages**– this will explore the first black holes and stars, and help to answer the question of what happened after the big bang and before the first stars and galaxies formed;
- **The origin and evolution of cosmic magnetism** – this will explore how magnetism affects the formation of stars and galaxies, and what maintains the present-day magnetic fields of galaxies, stars and planets;
- **Strong field tests of gravity using pulsars and black holes** – this will help to test whether Einstein's theory of general relativity is the last word on gravity, for example, whether its predictions for black holes are correct, and whether the cosmos is filled with a gravitational wave background;
- **Galaxy evolution, cosmology, and dark matter** – this will explore how galaxies are born and how they evolve, and seek a better understanding of the "dark energy" that fills the majority of the universe.

As flagged above, we do not propose trying to value advances in relation to these questions – equally we recognise that significant value would need to be attached to knowledge in these areas for the justification for the international initiative to make any sense. While costs will clearly be dependent on decisions on sites and technology still in progress, indicative costs of construction or of the order of $3 billion – with very substantial ongoing costs associated with operation, maintenance and upgrading of the facility across a design life of the order of 70 years.

[66] http://www.skatelescope.org/pages/page_genpub.htm

Clearly this is a high cost, big science opportunity to address possibly the most fundamental science questions we have. The high interest in participation amongst scientists is easily explained. The broader interest of the community in that science is suggested by the interest in other products of space exploration – including space vehicles that have probed the solar system and the recent successes in detecting planets outside the solar system and controversial suggestions of evidence of life on other planets.

O.2 Economic opportunity for Australia

The SKA project may well never 'pay for itself' unless high value is attached to the science outcomes. However, the prospects of Australian involvement as part of the consortium, contributing to costs and competing to be the host site, are actually a lot more promising. In theory at least, Australian investment in the SKA could create a surplus, while delivering access to a new natural resource in which Australia appears to be highly competitive.

There are several key reasons underpinning these assertions. Australia now has a very strong chance of being the host site for the telescope, driven by several factors:

- In principle, the proposed Australian layout appears preferable to the proposed South African layout, in terms of orientation and especially the ability to manage radio noise interference, in the quality of the science it could support.
  - This appears now to be largely uncontested, with discussion being about the adequacy, as opposed to the superiority, of the South African site.
  - It seems appropriate to recognise that Australia now has a potentially valuable 'natural resource' in the form of a large area of land with very low radio noise levels.
  - The layout involves Australia and New Zealand, two highly stable countries, with solid governance – attractive features relative to some of the locations proposed for the South African siting.
- Australia – and CSIRO – have been major players in radio astronomy almost from its outset; Australia has a strong radioastronomy community and a high international reputation.
- Australia has been a key driver of a number of the still highly promising technologies that could be integrated into the final design.
  - Notable here is a *field-of-view enhancement by focal-plane phased arrays*, a new technology largely developed by CSIRO and now the subject of close development and testing by an international consortium.
  - This and other technologies are to be tested and demonstrated, initially at existing radioastronomy facilities, notably the Parkes facility managed

by CSIRO and later at the Pathfinder facility being built in WA, and should be amenable to transfer across to the whole SKA, with very strong local support from the technology developers.

- Australia has existing radio astronomy facilities that are likely to be suited to integration into the SKA.
- The Australian Government is supporting selection of site based primarily on the science objectives.

This said, it is important to recognise that there is a lot of international sympathy for having a project of this scale sited in South Africa – raising funds may be easier for some countries with a project seen as having a 'development' function as well as a science function. This remains a 'risk factor' in any consideration of impact so far.

A decision on site is expected in 2012. Wherever the telescope is to be located, its construction and operation will require very substantial construction and infrastructure provision activity within the hosting country – accounting for a significant proportion of total project budget.

There is real potential for the external component of SKA funding delivering construction activity that is large in relation to Australia's contribution to costs:

- Provided that Australia's share of total costs is contained – with current expectations being that it would be of the order of 10 per cent
- Key components of the infrastructure, including very high speed and capacity broadband links and roads to the stations could offer much broader value through services to remote areas.
- The stations will require local support in general maintenance and electronics support services.
- If Australian technologies are chosen for key roles in the facility (irrespective of location), Australia would, under SKA protocols, retain wider rights in relation to the technologies – supporting opportunities for wider development of high end electronics and ICT activity in Australia.
  - There appear to be opportunities for strong crossover between the radio astronomy requirements and applications in commercial ICT, telecommunications and defence sciences.
- Work commenced earlier this year on upgrading NASA facilities at the CSIRO operated Canberra Deep Space Communications Complex (CDSCC) as part of global upgrading of the NASA Deep Space Network.
  - CDSCC supports one of three nodes to this network.
  - The 2005 ACIL Tasman SKA business case noted the synergies between the two facilities, and the potential for Australia's strong position to host the SKA supporting greater prospects for increased NASA investment in the DSN facilities in Australia. Effectively, we recognized the cumulative value of Australia's position in radio

astronomy to attract other external funding of radio astronomy activity within Australia – again with tangible spillovers in addition to the contribution to science.

- A requirement imposed by the SKA Consortium is that the facility will use an integrated green energy solution – a renewable and sustainable energy solution is mandated. Australia is well placed to achieve a green energy solution:
  - Current planning for the SKA in Australia is based in expectations of using a mix of optimised solar, photovoltaic and solar thermal solutions supported by remotely generated wind, wave, geothermal exchange or biomass energy.
  - Early demonstration, as part of the bidding process, will involve the power supply to the Pathfinder.
  - This offers opportunities both to have integrated solutions or components demonstrated, by companies from around the world, in Australia, and for systems for renewable energy delivery suited to Australia's remote areas to be developed and tested here.
  - This has obvious links into other parts of CSIRO, including the efforts in relation to climate change mitigation and adaptation.
  - The Federal Government has just announced that it will provide $47.3 million to develop the needed green energy technologies – and recognising additional value in helping to secure Australia's bid to host the SKA.

O.3 Australian Square Kilometre Array Pathfinder

The Australian Government has committed $111m to the construction of ASKAP in WA – at the site proposed to be the central hub of the SKA if located in Australia. CSIRO has also diverted funds into this investment, given its strategic significance for Australian radio astronomy, while the project has also secured strong involvement from scientists and engineers in the UK, Canada, Germany, as well as from institutions and industry partners within Australia.

The project involves construction of one of the world's most powerful radio telescopes – as research infrastructure of value in its own right, including direct support for the SKA project objectives listed earlier; as a platform for developing and demonstrating technologies for use in the SKA (whether located in Australia or not); and as a major first step in the roll out of the SKA in the event that Australia is chosen as the site. While still; under construction, ASKAP in June achieved 10 times the resolution of the Hubble Telescope. This followed linking of the main site to antennae arrays in NSW and New Zealand.

Regardless of outcome on the SKA siting decision, this facility will greatly strengthen Australia's position as a global leader in radio astronomy. However, it also contributes very substantially to Australia's prospects for being selected as the site for the SKA – adding substantially to the value of the infrastructure investment.

ACIL Tasman's 2005 modelling of the value of Australia's SKA strategy recognised the critical role to be played by ASKAP in enhancing Australia's prospects and the value of the strategy. These arguments were reinforced in probing the Astronomy Consortium case for NCRIS funding – that included significant support for ASKAP.

O.4 CSIRO contribution & counterfactual

CSIRO has been a key player in Australian radio astronomy from the outset. It has been the main institution driving Australia's engagement in the international process – co-ordinating the inputs of a range of other institutions, developing the initial business case to the Federal Government and being the key player in relation to the phased array technology being pursued as potentially a key part of the 'solution.

The Australian Telescope National Facility sits within CSIRO's astronomy and Space Science business unit and operates the Australian Telescope, consisting of the Compact Array at Narrabri and the Parkes and Mopra radio telescopes. It has a strong focus on the development of advanced technologies, suited to pushing out the capabilities of radio telescopes. It also operates the CDSCC complex, that is already seeing significant new investment by NASA.

Realistically, it is hard to imagine Australia having mounted a serious bid to host the SKA without the strong involvement and leadership offered by CSIRO – and without the facilities in history in radio astronomy in which CSIRO has played such an important role.

Of course, this is not the same as saying that CSIRO alone is responsible for Australia's current positioning ion the possibilities – it simply means that we consider that CSIRO's role has probably been critical to making the bid for siting in Australia, and serious assessment of Australian technologies for core parts of the SKA, credible.

It might be argued that, without CSIRO's involvement, a comparable position would have been developed across other institutions. This is possible, but the extensive facilities management requirements, and the multi-disciplinary, mission-oriented capabilities that underscore modern radio astronomy projects, all suggest that the capabilities and culture offered by CSIRO are likely to have made a major difference. We have judged that that difference has probably been critical to Australia being a serious contender on both siting and phased array technology.

O.5 Value indicators

The net value of these opportunities (excluding the value of the science) is tightly interwoven with the prospects for Australia being chosen as the host site and is strengthened by the prospects for significant use of Australian-based technology. This suggests scope for adding value through improvements to either or both of these.

The 2005 business case attempted to develop lower bound estimates of the tangible value of the SKA proceeding under various scenarios covering location and technology choice – with the latter assumed to have some implications for the former. ACIL Tasman developed an options model of the possibilities and used this to undertake an assessment of risks, opportunities and strategy.

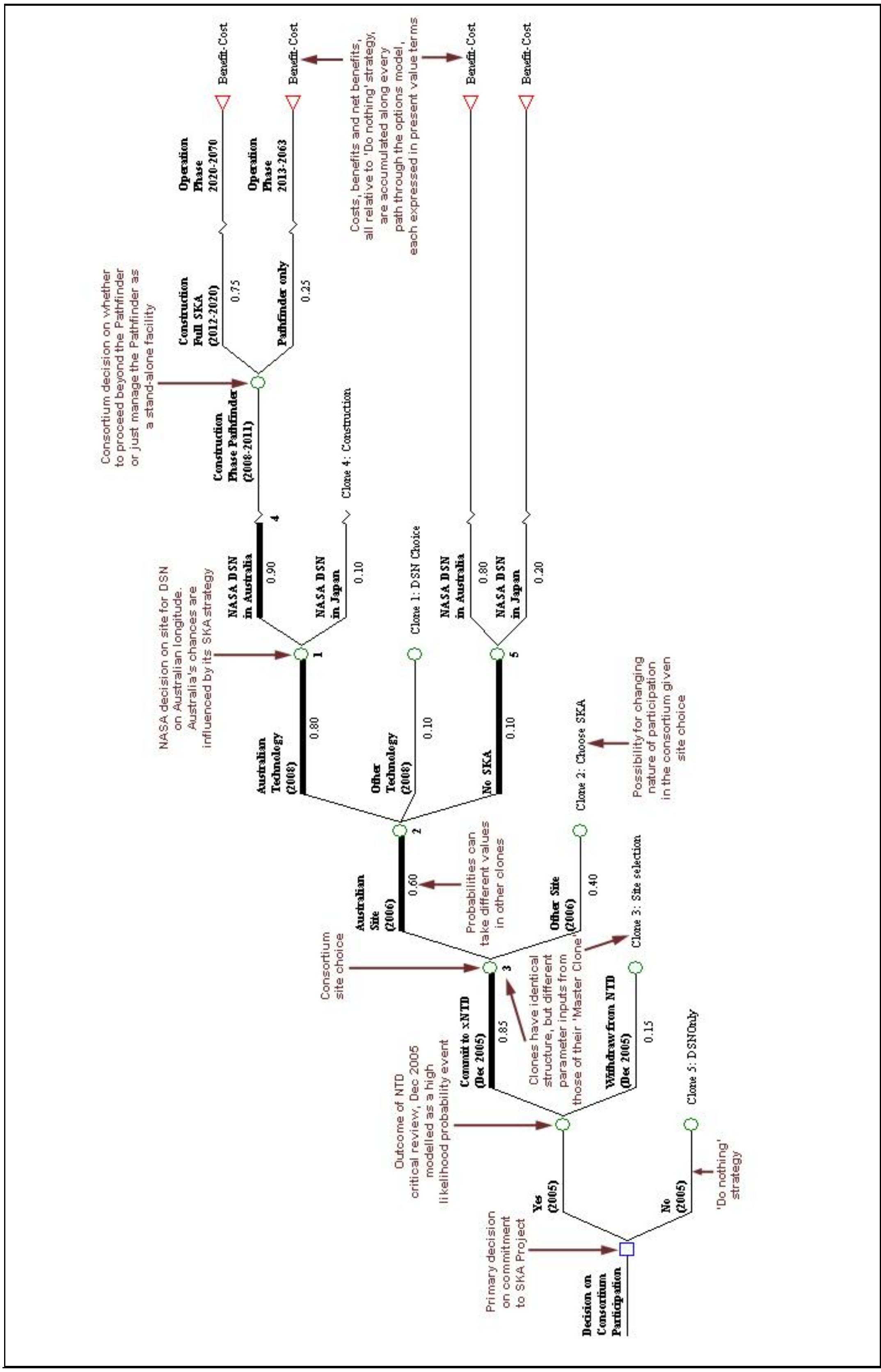
Clearly much has happened since then. However, in the context of a vignette demonstrating some specific impact and value propositions, we have not sought to do a comprehensive update of the model. Instead, we have revisited the old model, and reviewed the likely implications of more recent developments for overall value. These are intended to be indicative only – but we start from the position that the earlier modelling was deliberately extremely conservative in the assumptions it made – strongly favoring underestimation over risking overestimation.

The broad structure of the options model developed in 2005 is set out in Figure O1, which reproduces Figure 4 from the 2005 report. Were we starting from scratch, the model structure would be somewhat different from that set out in the Figure. Nonetheless, the model as it stands offers a stylized representation of possibilities. Actual commitment to the pathfinder has occurred earlier than had been envisaged, reflecting the decision to use the Pathfinder to strengthen the SKA siting bid and the perceived value of ASKAP in its own right. The DSN decisions have now been taken – but were assumed to be highly likely even in 2005.

The model tracks costs incurred, starting from 2005, and calculates lower bound estimates of net benefits under different scenarios in relation to siting decisions, technology choices etc.

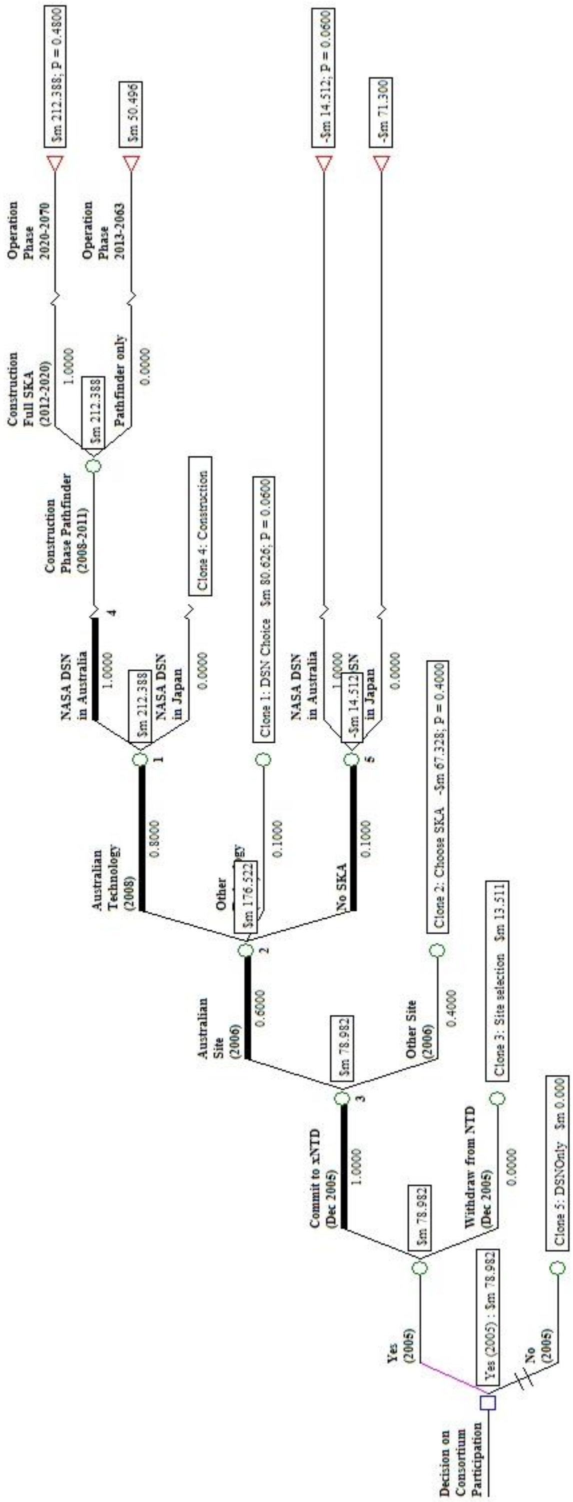
The structure of the model is shown in Figure O1.

Figure O1 **Overview of structure of the SKA options model**



Source: ACIL Tasman (2005)

Figure O2 **Indicative solution of options model, revised assumptions**



Source: if ACIL Tasman data

This is the same structure as the original model. As discussed above, starting from scratch, we would develop a somewhat different structure. However, in the context of a vignette, this structure appears reasonably suited to being updated to provide value indicators in relation to the more tangible costs and benefits.

To provide an indication of tangible value, we have rerun the model with a few tweaks to reflect more recent developments, including:

- The discount rate has been adjusted to 7% real, reflecting the base rate used throughout the current assessment. Given the long life of the SKA project, and the heavy up-front capital loading, choice of discount rates can make a big difference.
- Probability of the Pathfinder (ASKAP) proceeding has been set to 100 per cent

The original modelling lends itself to moving forward, through the major uncertainties, while keeping all the costs since 2005 locked in. The rerun model is shown in Figure O2. We stress that this is an indicator only, and relates only to the tangible benefits as modelled in the earlier work.

It excludes any value attached to the primary science objective of the project – to enhance greatly our understanding of our universe. This exclusion might be justified on the basis that these science objectives are likely to be broadly achieved, irrespective of whether Australia hosts the facility. However, the strong indications that Australia (with New Zealand) can offer a superior site, in terms of the science objectives, does suggest that at least a proportion of these science benefits are relevant to a balanced assessment. There would of course be substantial variation across the community in the value attached to the science objectives – but we would certainly expect it to be significant in aggregate.

Broadly speaking, the analysis of the more tangible benefits and costs suggests the following impact and value indicators:

- Inclusive of all costs incurred since 2005 and running forward on the assumption of Australia ultimately paying 10 per cent of SKA costs, the expected **net** tangible value of the tangible options that are now in place is conservatively of the order of $80m.
  - … Of course the values associated with the pure science which will be undertaken in the SKA will be on top of this expected net tangible value.
- This estimate is essentially a risk-weighted value, dependent mainly on the ultimate siting decision.

- We have inferred about a 60 per cent chance of the decision being for an Australian site, in which case the expected **net** tangible value would be about $176m.
- There is an assumed corresponding 40 per cent chance of the decision favouring a South African site, in which case our conservative assessment, in which we tend to underestimate tangible benefits, would have these falling short of costs, with the margin being somewhat less than $70 million.
  - … In this worst case scenario' it is important to recognise that this $70 million in *net* costs is probably high, would be spread over decades and would be offset by whatever value is attached to Australia's participation in producing the science outputs from this global science project.

We believe it would be inappropriate to attempt to size up the value and impact of this radio astronomy work based on these numbers. The reason for being involved in radio astronomy is the science. What the analysis strongly suggests is more as follows:

- CSIRO has substantially driven a process of accumulating capability and facilities, and planning for large-scale radio astronomy projects, that has opened up an opportunity for Australia to assume a central position in international radio astronomy for decades to come.
- There are very good prospects for this opportunity to now be realised in a way that is 'cash flow positive' for Australia, comparing tangible benefits to costs, and ignoring the value of the science outcomes – the main reason for the project proceeding.
- Even if Australia is not selected, the worst case scenario implies modest net tangible cost over some decades, with the possibility that spin-offs arising from the technologies and the capabilities could turn this around – and Australia would still gain access to the facility and the scope for contributing to the science outcomes.

We also note (as flagged earlier) that the Federal Government has as recently as mid-June indicated strong commitment to the project via the injection of additional resources to support the development of appropriate green energy sources and, earlier in the year, involvement in negotiating a land use agreement with Aboriginal groups, covering 130 square kilometres around the proposed site for the SKA hub.

Viewed in these terms, we believe CSIRO has been strongly instrumental in opening up a particularly attractive opportunity for Australia to engage in 'big science'. It appears to play strongly to Australia's *competitiveness in radio quiet sites*, in relevant technologies and in large research infrastructure management. It appears to entail large upside and modest downside, in tangible terms – and offers as a minimal legacy what will be one of the most powerful radio telescopes in the world, probably for decades, located in Australia with both stand-alone value as a world class facility a key role to play in relation to the science objectives of the SKA project. It will also be operational sooner than has been assumed in the above modelling.

Taking into account the conservatism in the assessment of tangible value, plus the absence of any science values, the indicator option value of $80m+ could be considered highly conservative. The picture is not changed substantially under plausible variations in the discount rate.

Perhaps the main 'threat' is that financial turmoil, especially in Europe, may challenge the capacity of the International Consortium to proceed without a significant delay. Were that to happen, Australia would have, for much longer than has been planned, an instrument that would arguably be the most powerful radio astronomy facility in the world – and certainly one at the leading edge technologically. The way that funding is being structured would imply some financial risk for Australia – because the ASKAP is being substantially funded by Australia in expectations of this being an offset to a later move to the SKA – unless this up-front investment were seen as largely justifiable in its own right, by the science objectives and by the infrastructure investments that will be needed in any case to support ASKAP. The indicative modelling attributes less value to this infrastructure investment because of the way it assumed later commitment to ASKAP, conditional on the SKA being sited in Australia.

The modelling does factor in a 10 per cent chance of the project being shelved. That specification was originally designed to deal with the prospect that the project might fail on technical grounds – inability to develop a viable technology to make the SKA possible. That risk has reduced greatly since the modelling was originally done, but the parameter can be viewed as acting as a proxy also for the risks of the project not proceeding because of international financial strictures or other reasons.

Although this modelling is no longer a perfect fit for the strategy being pursued, it has been used to provide some indicator values and is probably excessively conservative in relation to expected tangible returns. Superficially, the indicators suggest that the SKA strategy may well be capable of delivering to Australia upside well in excess of downside, and to be essentially 'self funding' at a national economy level. This reflects special characteristics of this large science project and the fact that Australia has some special competitiveness to offer. Some of this competitiveness rests with the geography of the country and settlement patterns. However, a significant element in the competitiveness has undoubtedly been the legacy of Australian involvement in radio astronomy, with strong leadership from CSIRO, and the capacity CSIRO offered to coordinate a technology package to address major design issues with the SKA concept.

We are not suggesting a general proposition that large science, directed at relatively pure science objectives, can normally be self funding if assessed in terms of impact on the measured economy – royalty streams, GDP, incomes per capita etc. Globally, the SKA will not do this. If government investment were to be driven solely by these sorts of performance indicators, then it would probably support a substantial withdrawal from basic research – relying more on 'free riding' but also withdrawing from substantial areas of the arts and heritage and would at a more extreme point suggest serious probing of investments in areas such as aged care and care for the disabled.

The fact is that society's values are complex and multidimensional and extend well beyond commercial and economic. Cultural values are important, and a part of Australia's cultural legacy has been a history of 'punching above its weight' in science, including radio astronomy.

The main purposes in reviewing value and impact in relation to the SKA is to highlight the way that CSIRO has helped to position us well in areas of science where Australia has a strong tradition and may now have special competitive advantage in a small subset of the 'big science' projects being planned around the world.

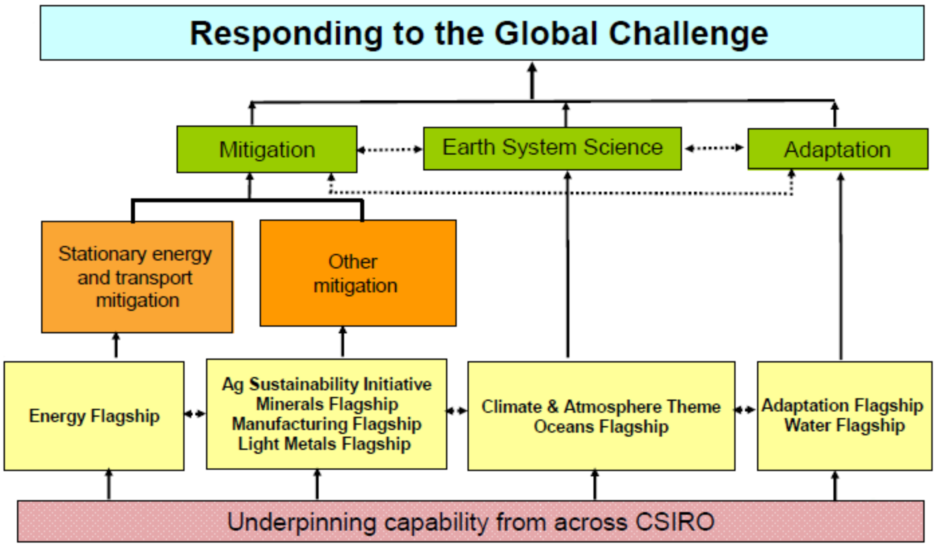
P Cross-CSIRO climate strategy

The Draft report by the Garnaut Climate Change Review summed up the global climate change problem very well. That report stated:

> Climate change is a diabolical policy problem. It is harder than any other issue of high importance that has come before our polity in living memory[67]

With its breadth and depth of capabilities and expertise CSIRO is in a unique position to respond to large scale problems of this kind. Through five of its Flagships, supported by the skills of researchers from across the spectrum of its capabilities, CSIRO is researching ways to mitigate climate change and ways in which Australia can adapt to the changes in our climate that are in effect already "built into the system" by virtue of global greenhouse gas emissions to date. At the same time, CSIRO is continuing to carry out research in order to continually improve our understanding of the earth's climate systems. Figure P1 illustrates the scope of CSIRO's activity.

Figure P1 **The breadth and depth of CSIRO work on climate change**



Data source: Personal communication CSIRO, June 2010

The work of the CSIRO aligns well with the options paradigm we have used in examining the value delivered as a result of the investment made. CSIRO's investment in innovation is creating *options,* namely options to:

- deliver valuable outcomes that offer expanded levers for mitigation and adaptation while commonly also delivering other valuable functionality;

[67] Garnaut Climate Change Review Draft Report, June 2008

- eg, geopolymers, UltraBattery, lower energy light metal processing, climate-ready crops, biochar in soils and their use in steel making etc.

- better manage serious residual risks linked to climate trends;
  - such as the risks associated with inundation and bushfires, increased peak power demand etc.

CSIRO's work is delivering far greater flexibility in dealing with climate change. Australia can identify and capture opportunities, better manage risks, limit (potentially expensive or unnecessary) commitment until greater certainty about eventual outcomes is available and obtain more and better information to reduce uncertainty. CSIRO's contribution to the expansion of available options shows real promise of allowing for cheaper and/or stronger mitigations strategy to be pursued while protecting Australian competitiveness, while also limiting damage through more cost effective and better informed adaptation measures. Importantly, several of the innovations flowing from CSIRO's research show real promise in contributing – as part of a much larger global innovation package – to a shift in incentives for greater and earlier global measures to mitigate emissions.

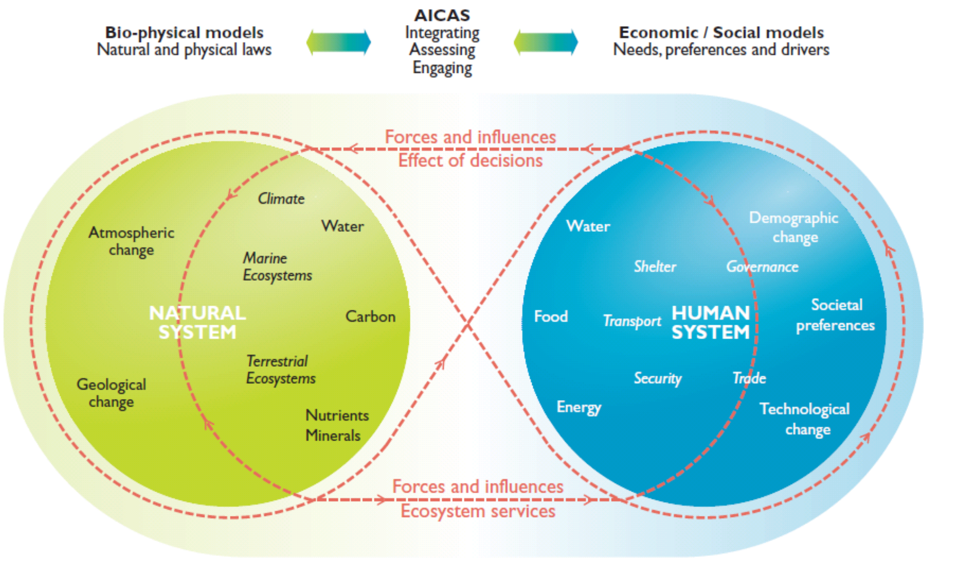
At the same time CSIRO continues to develop and maintain a suite of capabilities to equip it to deal with evolving and emerging opportunities and threats. The proposed Australian Integrated Carbon Assessment Service (AICAS) is one such proposed capability. AICAS is intended to be a new collaboration across Australia's leading bio-physical and socio-economic research institutions that will deliver more rigorous, better integrated and more relevant science to decision makers. AICAS is intended to provide Australia with a much better understanding of how our natural and urban environments, the energy sector and our economy interact across the entire system. These three areas interact strongly in determining the right balance of measures – across mitigation, adaptation and further research and innovation – especially where the climate challenge is approached as a risk management challenge in which an options-based strategy is to be pursued.

Importantly, while many of the capabilities that would make up AICAS already exist, they are largely being pursued in isolation from each other. Creating AICAS is intended to speed the integration of these capabilities and accelerate the provision of better quality and more complete advice to policy makers.

This stage in the evolution of CSIRO's work is a logical progression in a sequence of effort that has moved from a focus on the science of climate change and a probing of individual instruments, through to a systematic improvement in mitigation and adaptation options, and now finally to the development of an emerging capacity for serious consideration of 'optimised' strategy across both sets of instruments, taking into account the quality of the climate science.

CSIRO will, of course, not be the only player in AICAS. It will again draw great strength from the nature of the collaboration involved. However, based on the case study work already considered, we see high potential in the breadth and depth of skills that CSIRO has, the potential this offers for greater coherence and focus, and again, the greater capacity to bring a critical mass of appropriate skills to bear early on a complex problem where early action can have high value but, given current uncertainties, can also bring high risk.

Figure P2 **Architecture of the proposed AICAS**



Data source: AICAS draft prospectus

While we have not specifically evaluated the proposed AICAS, we anticipate significant value would emerge from this evolution of CSIRO's activities, through its ability to provide a better basis for evolving climate policy. Certainly, the scale of the costs that Australia and other countries face, the scale of the potential gains from sound strategy and the high uncertainties, suggests that very large value could be delivered as an outcome of CSIRO's efforts. That value will be delivered by way of cost reductions, improved outcomes and insurance against serious error in policy decisions. Further, much of the needed optimisation of the response to climate change is likely to be country- and region-specific, and this is where the capability and focus that CSIRO offers could make a substantial difference.